In modern electrical practice, heavy duty switchgear plays an increasingly important part. Here is the circuit breaker assembly section of a leading manufacturer.

General heavy-duty switchgear is here shown in the assembly stage in a modern works. The size and weight of this apparatus necessitates allocation of much space and powerful lifting gear for assembly purposes.

HEAVY SWITCHGEAR SECTIONS OF A LARGE NORTH OF ENGLAND WORKS

Frontispiece Vol IV Photographs by Reyrolle & Co., Ltd

THE ELECTRICAL ENCYCLOPEDIA

A Handbook of Modern Electrical Practice for The Working Electrician

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ELECTRICAL EDUCATION AND EMPLOYMENT

Practical and Theoretical Training in the Electrical Engineering Industry

By Philip Kemp, M.Sc.(Tech.), M.I.E.E., Head of The Polytechnic School of Engineering

ELECTRICAL engineering is a skilled profession, and to achieve success in it at the present day a proper training is essential. In the early days, when it was largely an empirical art, men grew up in the industry, with no specialized initial training, gathering their experience in an experimental way as they went along. Their efforts were often of the trial and error type. At the present time such a mode of procedure does not lead to success even if disaster is avoided. Technical knowledge has reached such a pitch, and competition is so keen, that an electrical engineer must have surer knowledge on which to base his actions and decisions. The day of the so-called "practical" man, who often decried theoretical knowledge well knowing himself to be woefully lacking in that direction, is gone, never to return Equally, the theoretician, the "paper" engineer without practical experience, is inadequate in this modern complex world. What is demanded is a proper balance of theoretical training and practical experience. Neither is sufficient in itself.

THE education of an electrical engineer is thus seen to consist of two parts: (1) theoretical and (2) practical. The theoretical and technical part of the training is best obtained at a University or Technical College, where the student may study under the personal supervision of men skilled in their particular art. Real practical experience can only be gained under actual working conditions. A student can usefully be introduced to workshop practice in his college, but he can never spare sufficient time to this aspect of his work for real proficiency.

Problems of Modern Technical Training

THE technical training of a prospective electrical engineer is a problem to which much thought has been given. The first problem is whether the theoretical and technical part or the practical part of the training should come first. Both methods have points to recommend them. If a practical apprenticeship is served before the college course is undertaken, the student will appreciate to a much greater degree the practical implications of much that he is taught. He has acquired an engineering sense.

ON the other hand he will, to some extent, have lost the capacity for study. The hiatus between his school and his college days, a matter of years, is such that he has frequently got out of the way of studying, and a return to the student mode of life often demands a very serious effort of will power. In a number of cases this effort seems to be beyond the capacity of the student to make. As a consequence his technical studies suffer. On the whole, the consensus of opinion in this country is that it is better to carry straight on with the technical studies immediately on leaving school, and to acquire practical experience by a later apprenticeship.

The "Sandwich" System of Training

A NUMBER of eminent engineers recommend a course which is a compromise between the above two schemes, the so-called "sandwich" system. The trainee spends alternative years in college and works until his period of training is complete. Alternately he may spend the winter months in college and the summer months in works. Both systems are followed. Such a scheme, for its successful operation, demands a close co-operation between the college and a number of engineering factories, permitting an easy flow of trainees from one to the other. Practical difficulties are apt to occur on account of the strain which may be experienced by the engineering firms in absorbing all the candidates in times of industrial depression.

Apprenticeship and Evening Studies Compared

In many cases a young man must necessarily carry on his studies simultaneously with serving his apprenticeship. He carries on his ordinary vocation during the day and turns to his studies in the evening. This system can never be so satisfactory as that embracing a full-time course of study followed, or preceded, by a course of apprenticeship.

In the first place the student is tired when he comes to his studies, having already presumably done a day's work, whereas the full-time student comes to his studies in the morning when he is fresh. Again, a part-time evening course usually covers some eight hours per week, arranged over three evenings, as against, say, thirty hours per week arranged over five days. The full-time student can devote any or all of his evenings to private study in connexion with his course, whilst the evening student can only devote the remaining evenings to study. This leaves out of account entirely all time spent in recreation and leisure, and these are essential if a student is to keep up with what is admitted to be a heavy programme.

At the present day the total time recommended for the period of training in this country is three years in college followed by a recognized apprenticeship course of two or three years for the full-time student, and five years evening classes carried on simultaneously with an apprenticeship lasting an equal time. It is interesting to note, by the way, that the evening class type of training does not find favour on the Continent, and seems to be largely British in its origin.

There is another type of training which is open to those to whom it appeals, *viz.* that offered by the correspondence college. This cannot be recommended except in those cases where it is impossible for a student to attend in person. In a correspondence course, personal contact with the lecturers and tutors is necessarily absent, and this human touch is extremely valuable as an aid to engineering education. A letter or a gramophone record can never replace the actual teacher. Again, the laboratory and workshop play an extraordinarily important part in the technical education of a student, and should by no means be omitted.

An Education Never Complete

The engineer should realize that his education is never complete. Change and advancement are constantly taking place, and an engineer must either march with the times or else rapidly become a back number. He must either advance or fall back; he cannot stand still. To this end he must keep himself in touch with modern developments through the medium of the technical press and by the aid of the various professional engineering societies. Membership in one grade or another of at least one of the leading engineering societies is highly desirable, if not essential. The premier body which caters in this way for the electrical profession is the Institution of Electrical Engineers, and every young electrical engineer should aim at attaining either full or associate membership.

There are other bodies of a similar type having a more sectional or specialized interest, membership of which can be extremely valuable. It should be remarked that corporate membership, *i.e.* full or associate membership, of the Institution of Electrical Engineers demands, in common with a number of other professional engineering societies, that the candidate shall have held a post of responsibility in the industry for a stated time, in addition to having been trained both technically and practically. The candidate must also pass an examination of a high standard, if he has not already passed one of the exempting examinations, a list of which can be obtained from the Institution.

A University degree in Engineering is also of great value, and carries considerable weight in many directions. To obtain this qualification, the candidate must study for at least three years in a University or College recognized for the purpose. The standard of entry for such a course is that of matriculation. In the sole case of London University a B.Sc. (Engineering) degree can be obtained by what is called an external student as well as internally, *i.e.* by a student not attached to one of the recognized internal colleges.

Essential Qualifications

THE technical qualifications discussed above are of great value when seeking a post in competition with others. In fact, possession of certain of these is specified in many advertisements. This is particularly the case in connexion with government and municipal posts, whilst many of the larger of the industrial manufacturing firms will not take on student-apprentices unless they are in possession of some kind of approved diploma. These paper qualifications are particularly important to the young engineer, as they form his principal claim to proficiency in his profession. To engineers who are a little older and who have progressed somewhat along the road to success, the question of experience gained is of more vital importance. The question is now what has a man done, rather than what can he do, and the record of work actually accomplished will be the prime factor on which he is judged.

The Choice of a Specialized Career

THERE are many branches of electrical engineering, and the embryo engineer must make some kind of choice quite early in his career. It is not advisable, however, to begin to specialize at too early a date. This should certainly not be done prior to the completion of the college part of the education. In fact, in the normal course of things, all engineering students study the same syllabus in their first year, whether studying for the civil, mechanical, or electrical branches of their profession. In their second year they begin to devote more time to their own part of the subject, whilst in the third year the bulk of their time is spent in this direction. This is not what is meant by specializing in the sense that it is here used. After he leaves college, the student-apprentice enters a works of some kind, doing work of a general character.

The specialization only comes later. He must ultimately choose whether he wishes to enter the design, manufacturing, sales, etc., side of the company, or whether he wishes to employ himself on the public supply, contracting, or utilization side.

Then, again, there is a rough and ready division between what is called " heavy " and " light " electrical engineering, or, alternatively, into power and communication engineering, including in the latter term all commercial telegraphy and telephony, wireless (both commercial and broadcast), electrical music and public address systems, not excluding talking films and television. It is in the last large group that the greatest changes have taken place in the past ten years or so. Obviously the technique for such branches of the profession is very different from that which needs to be acquired for, say, the manufacture of giant turbo-alternators or the construction of long-distance transmission lines.

Limitations of the Purely "Practical" Man

THE above remarks refer principally to the fully qualified and technically trained engineer, but there is a large class who do not aim at such a broad technical knowledge, relying chiefly on the practical aspect of their craft. It is a prime mistake, however, in these complex and competitive days, to neglect entirely the theoretical and technical side of the subject. It is not in this way that promotion lies. To gain advancement, one must have opportunity and the capacity to profit by that opportunity when it occurs, and the young engineer or artisan must be prepared to meet new conditions as they arise. There are many men who can do a job that they have done before. The man who is going to get on is the one who can do a job that he has not done before, and make a success of it. Routine work carries routine pay, and to get more than this requires something more than the capacity for repetition.

AGAIN, it must be remembered that engineering work has to be carried out on an economic basis, and that needless expenditure is a sign of inefficiency. Indeed, one terse American definition of an engineer is that he is a man who can do for one dollar what any fool can do for two.

It is thus seen that to have the capacity for success, an engineer must have a love and aptitude for his work, he must be properly trained and experienced, and finally he must have the opportunity and the ability to profit by it when it occurs.

THE ELECTRICAL ENCYCLOPEDIA

A Handbook for the Working Electrician

VOLUME IV

SALIENT POLE GENERATOR. Or projecting pole generators, as opposed to those in which the rotor has a cylindrical core with the winding embedded in slots. The salient poles consist of separate radial projections each with its own pole piece and field coil. Such a construction is sometimes adopted in four-pole alternators (*q.v.*), and is commonly used in D.C. generators (*q.v.*). The high speeds attained in modern turbo-alternators involving excessive mechanical stress due to centrifugal force prohibit their use and led to the adoption of the rotor construction previously mentioned.

SATURATION. Word used in a number of connexions in electrical and scientific work. In dealing with primary cells, for example, as the Daniell cell or the Leclanché cell, some such expression as a saturated solution of copper sulphate or a saturated solution of ammonium chloride is used. A solution is said to be saturated, or to have reached its saturation point, when the liquid solvent contains as much of the substance as it is possible to dissolve in it.

In the case of an ordinary three-electrode valve, or a gaseous discharge tube, the number of electrons emitted from the filament depends upon its temperature, and increases as the temperature is raised. There comes a time, however, when the plate will be taking the maximum amount of electrons it can from the filament, and by suitably arranging the positive potential of the plate with reference to the filament it is taking all the electrons emitted by the filament and passing through the electric field surrounding it. This is called the saturation point.

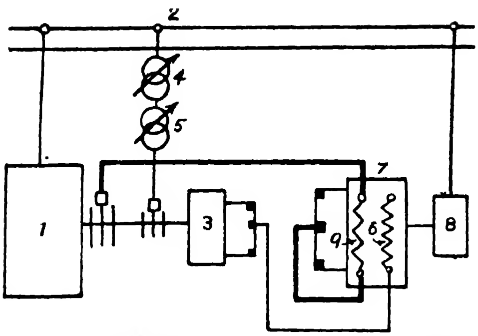
The chief application of the term, however, is to that magnetic condition of a body of iron when it is no longer possible to increase the intensity of magnetization by increase in the magnetizing force. This occurs when the B-H curve (*q.v.*) attains its peak and flattens out into a practically horizontal line. *See also* Hysteresis; Iron.

SATURATION CURRENT. Of a thermionic valve. The more or less clearly defined maximum value which can be reached by the feed current of a valve for a given condition of filament temperature under non-oscillating conditions. Applied also to that value of current in a gaseous discharge tube at which a change in the applied voltage causes no change in the current. *See* Saturation ; Valve.

SCARFED JOINT. One of the many forms which can be applied to jointing cables and connexions, described under the heading Joints and Jointing. The merit of the scarfed joint is that the ultimate diameter of the cable or conductor is not increased, and the two ends to be joined are bevelled away to allow greater surface contact at the joint. An illustration of this joint appears in page 707.

SCHERBIUS MACHINE. The power factor of a synchronous motor (*q.v.*) can be varied by adjusting the excitation, whereas that of an induction motor depends only on the design and cannot be varied. The Scherbius machine allows of extending the above advantage, and incidentally others, to the induction motor without interfering with its asynchronous running.

The induction motor (*q.v.*) is a form of transformer in which the stator induces an E.M.F. in the rotor, the value and frequency of which increase with the load. The current in the rotor depends on the value of the induced E.M.F., and on the constants of the rotor circuit. As this is always reactive, the current lags on the voltage ; the primary or stator current thus lags also.



SCHERBIUS MACHINE. Fig. 1. Simple application of Scherbius machine to an induction motor. (1) Induction motor; (2) bus-bars; (3) frequency changer; (4) and (5) induction regulators; (6) field winding; (7) Scherbius machine; (8) driving motor; (9) compensating winding.

It is possible, however, to use the rotor as primary and induce an E.M.F. in the stator. It is upon this principle that all Scherbius machines work.

Consider the arrangement shown in Fig. 1. On the shaft of the induction motor 1 is a frequency converter 3 (*q.v.*), fed from 2 by two induction regulators (*q.v.*) in series, 4 and 5. As this rotates at a speed proportional to $(f-s)$, where f is the supply frequency and s the slip frequency, it generates a voltage of frequency s, the value and phase of which can be adjusted by 4 and 5. It supplies the exciter winding 6 of the Scherbius machine 7. This has a field winding and a D.C. armature and commutator. It is driven by an auxiliary motor 8. As its field current varies with slip frequency it generates an E.M.F. of the same frequency and of magnitude and phase determined by the setting of 4 and 5. This E.M.F. is introduced or "injected" into the rotor circuit of 1 by connecting its slip-rings to the commutator of 7. The compensating winding 9, on 7, neutralizes the armature reaction.

If the injected E.M.F. leads on the normal slip E.M.F., the component of current due to the injected E.M.F. leads on the normal rotor current, and induces a corresponding leading current component in the stator. The stator power factor will thus more nearly approach unity and even lead on the voltage, the machine supplying wattless current to the supply network.

It is also possible by suitable arrangements to render the load of the induction machine independent of its slip, or make it vary in any desired manner as a function of the slip. This is done in the case of synchronous-asynchronous motor generator sets (*q.v.*), used for system coupling, when it is desired to render the power transferred from one system to the other independent of frequency changes in either.

Where the only object is the improvement of the power factor of an induction motor (phase advancing, *q.v.*) the arrangement may be simplified by driving the exciter (1, Fig. 2) from the motor shaft and exciting it directly from the main motor (2) slip-rings. As the rotor voltage and frequency of 1 increase always in the same proportion and the reactance of the field winding 3 of the exciter 1 increases proportionately to the applied frequency (*see* Reactance), the current in 3 remains substantially constant. The injected E.M.F. is therefore also nearly constant, so that the power factor of the motor is high even on very light loads (this advantage is not shared, for instance, by the Leblanc phase advancer). A compensating winding 4 is used to neutralize the armature reaction.

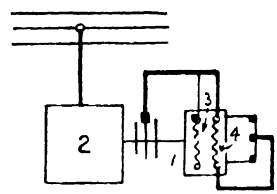
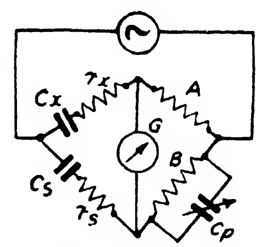


Fig. 2. Principle of shunt phase-advancer. (1) Phase advancer; (2) induction motor; (3) shunt winding; (4) compensating winding.

SCHERING BRIDGE. Employed in the measurement of dielectric losses and power factor of cables, insulators, etc., at high voltages. The circuit for power factor measurement, as illustrated on left. is also suitable for measuring dielectric loss. The underlying principle is that of the classical Wheatstone Bridge (*q.v.*), with modifications to yield the phase angle, and to adapt the bridge for use at high voltages. The low voltage standard condenser C_s is in parallel with the dielectric C_x and one of the resistance arms is shunted by means of a variable condenser C_p to obtain phase adjustment. When balance is obtained with zero deflection in the galvanometer $C_x = C_s \times$ a constant

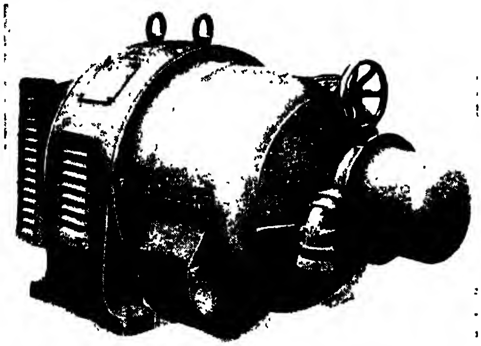


SCHERING BRIDGE. Connexions for power factor and dielectric loss measurements.

depending on the resistance ratio arms and the variable condenser C_p. *See* Bridge; Carey Foster Bridge.

SCHRAGE MOTOR. A polyphase A.C. commutator motor in which speed and power factor control are provided by means of movable brushes.

The rotor of the motor resembles the rotor of a rotary converter. Three (or other) phase A.C. is supplied to slip-rings on the rotor spindle and is collected from a commutator also mounted on the rotor spindle. Two rotor windings are usually provided. One, connected to the slip-ring, is called the primary, that connected to the commutator, the regulating winding.



SCHRAGE MOTOR. Fig. 1. A variable speed commutator alternating current motor.
The British Thomson-Houston Co., Ltd

Each pair of brushes is connected across one of the phase windings of the stator. The distance apart of each pair can be varied. If they are close to each other the voltage applied by them is small and can be reduced to zero by putting them on the same commutator segments. This is really equivalent to short-circuiting the stator windings. Under these conditions the machine runs like an ordinary induction motor with short-circuited rotor windings except that the windings corresponding to the rotor of the induction motor are stationary and those corresponding to the stator are moving.

Speed Control. If the brushes are separated a voltage difference appears according to the number of commutator segments that they span. Generally this voltage is alternating unless the rotor is running at exactly synchronous speed without slip when it is direct, just as it is at the brushes of a rotary converter. At synchronous speed the frequency is proportional to the slip. The voltage applied to the stator windings will assist that induced by the rotor windings if the brushes are separated in one direction and oppose it if they are separated in the other, causing a gain of speed in one case and a loss in the other. This gives control of speed without power waste.

Variation of the brush positions also enables the power factor of the current taken from the mains to be controlled. The motor can be run at leading power factor if required for phase correction, and at speeds either greater or less than synchronism.

Fig. 4 shows that the machine is primarily an inverted induction motor, *i.e.* the primary winding is on the rotor and the secondary on the stator. The regulating winding is provided, and is connected to the commutator, in a similar manner to that used in D.C. machines, and for convenience is wound in the same rotor slots as the primary windings, the voltage in it being obtained inductively from the primary windings. The frequency of the voltage induced in the regulating winding is the supply frequency, but it becomes slip frequency at the brushes where it is the same frequency as the E.M.F. of rotation in the secondary winding. The voltage on the commutator is therefore kept low whilst still permitting the primary winding to be supplied direct from a relatively high line voltage.

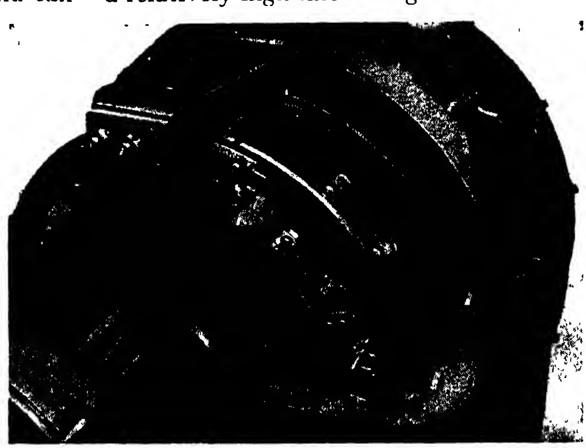
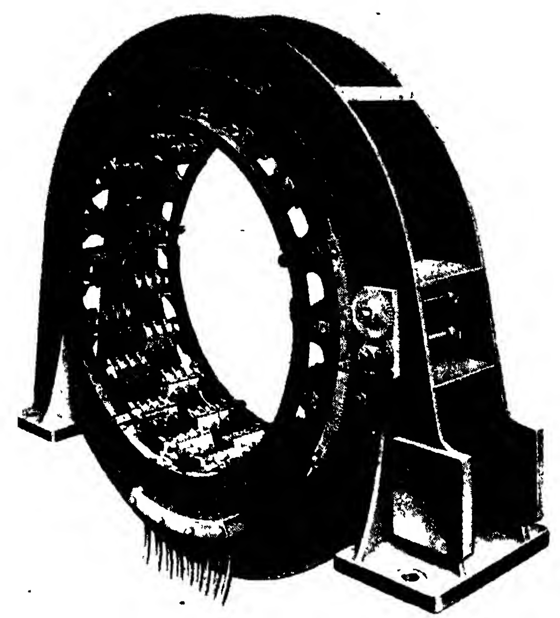


Fig. 2. The commutator and brush-gear of a Schrage motor, showing rack-clamping bolts and position pointers.
The British Thomson-Houston Co., Ltd.



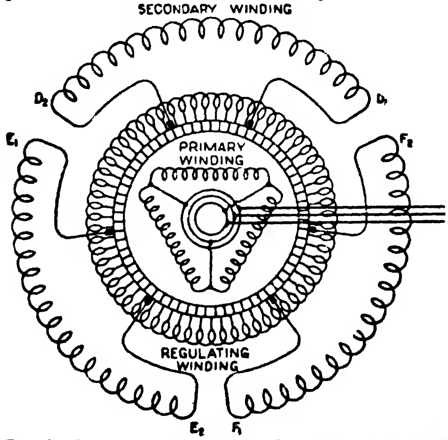
SCHRAGE MOTOR. Fig. 3. The commutator brush-gear in separate yoke, as used with large motors. Differential pinions are seen on the right.
The British Thomson-Houston Co., Ltd

On the actual motor (Fig. 2) the brush-gear is arranged on two separate sets of rockers connected together by means of pinions and racks (Fig. 3), the starts of all secondary phases being connected to the brushes on one rocker and the ends to the other rocker. Speed control is obtained by brush rocking through the rack and pinion gear, either manually or automatically. The speed range is limited by the power factor, and is usually of the order of 3/1. Whilst the speed regulation is good, the total drop in voltage between no load and full load is only 5–10 per cent. for any speed within the range.

Control of Power Factor. The power factor is nearly unity at super-synchronous speeds, but falls off at sub-synchronous speeds. It can be improved by shifting the axes of the brushes, this having the added advantage of increasing both the starting and maximum torque. High values for the former are possible, so that the starting conditions are good. The input to the motor being practically proportional to the output at all speeds, the efficiency is high over the complete speed range.

The limiting feature of this motor is the voltage between commutator segments, which, being short-circuited by the brushes, must be kept low. It is proportional amongst other things to the supply frequency, so that larger-sized machines are possible on the lower supply frequencies. Motors of 150 b.h.p. on 50 cycles and 600 b.h.p. on 25 cycles are in commission.

Their cost is comparatively high, but in cases where speed control is required the lessened cost of operating compared with other motors, *i.e.* resistance-controlled induction motors, somewhat discounts this high initial cost. It is utilized, therefore, for driving paper-making machinery, newspaper printing and calico printing



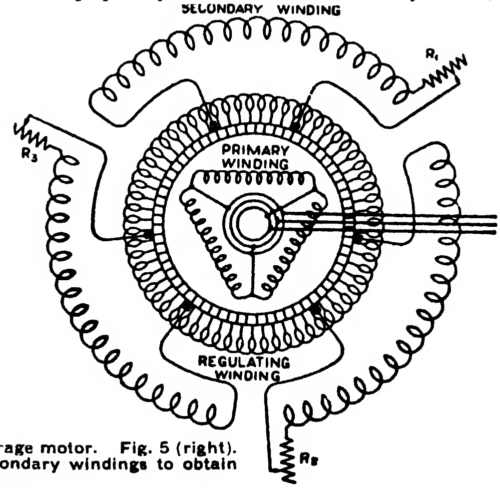


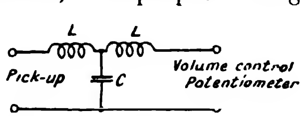
Fig. 4. Normal arrangement of the windings of the Schrage motor. Fig. 5 (right). Shows how resistances R, R_2 R_3 are inserted in secondary windings to obtain creeping speeds.
The British Thomson-Houston Co., Ltd

machines, machine tools, lifts, hydraulic pumps, etc. *See* Repulsion Motor.

SCOTT CONNEXION. A method of interconnecting two transformers to enable them to provide 3-phase from 2-phase supply or vice versa. A comparison with the Steinmetz connexion is illustrated under that heading. One terminal of one transformer on the 3-phase side is connected to the mid-point of the winding of the second transformer. The main terminals of the latter serve as two of the 3-phase line terminals and the remaining terminal of the first transformer is the third of these line terminals. On the 2-phase side, the transformer windings are usually kept separate, though they may be connected at one point if so desired. To obtain equal voltages in the two 2-phase windings with equal number of turns, the ratio of the 3-phase windings of the first and second transformers must be as $\sqrt{3} : 2$. The greater ratio of the secondary volts to primary volts in the first transformer makes the two secondary voltages equal.

An important application of this method of connexion is in single-phase electric furnace supply. The balancing of the load with two similar furnaces is facilitated, three being required with normal transformation. *See* Phase Transformer ; Transformer.

SCRATCH FILTER. A low-pass filter with a cut-off frequency of about 4,000 cycles per second used in conjunction with a pick-up in electrical reproduction from gramophone records, the purpose being to eliminate the noise made by the needle scratch. A simple filter circuit is shown.



SCRATCH FILTER. Simple circuit for elimination of needle scratch in electrical reproduction.

Although the system is quite effective in reducing scratch noise to a negligible level, it has one outstanding disadvantage in that it impairs the quality of the reproduction. For not only does it cut out the scratch noise, but also all frequencies above the cut-off value in the recording. The elimination of the highest notes and the overtones of violins, etc., naturally results in a somewhat muffled reproduction, the characteristic timbre of musical instruments being lost.

Modern records are remarkably free from scratch noise, and with them a scratch filter is not justified. It is, however, an advantage to have a scratch filter for use with older records and those becoming somewhat worn, with a switch to cut it out when new records are played.

SCREENED CABLE. To protect the conductors from the inductive effects of neighbouring cores, and to even out the electrical stress in the dielectric, thereby minimising risk of breakdown, cables are often provided with a screen of copper tape wound over the insulation, covering each conductor. An illustration of a screened cable appears in Fig 9, page 174. *See* Cable.

SCREENING. The restriction of electric or magnetic effects to specific areas of influence, by interposing electric or magnetic conductors between the part of any circuit in which these effects are occurring and the section they must not be allowed to affect. Two forms of screening exist—magnetic and electric. The former is effected by the interposition of iron between the two portions of the circuit where magnetic effects are to be restricted (*see* Shielding) ; whilst electric screening is carried out by using a good conductor such as copper sheet. If it is required to exclude both electric and magnetic effects from any particular circuit, both iron and copper should be used, otherwise complete screening is not effected. It is also advisable to earth the screens.

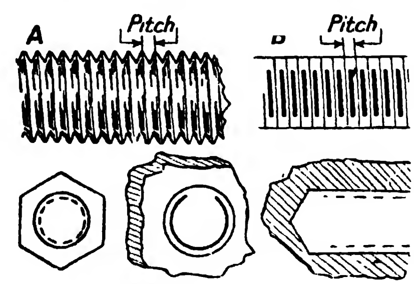
Another form of screening occurs in radio communication. Some high hills, land and even clouds often lie in the path of the waves, and are of such a character that they screen the receiver from the transmitter (*see* Blind Spots). It is not essential in these cases for the objects acting as screens to be themselves conductors of either electricity or magnetism to any practical degree. The angle of incidence of the waves often decides whether or no there will be screening, although when clouds act in this way they are electrically charged.

SCREWED CONDUIT. Metal tubing used for carrying electric cables and made up into lengths that are pipe screw threaded. Joints between sections are made by fitting the lengths of screwed conduit or tubing into threaded jointing

pieces. This form of conduit is so named to differentiate it from slip conduit. By its means there is ensured a nearly perfect continuity to earth throughout the system. Standard conduit sizes are ½ in., ⅝ in., and 1 in., etc., for power cables. *See* Conduit and Conduit Fittings; Wiring.

SCREW THREADS. Bolts and nuts formed with V-shaped screw threads are extensively used in all branches of engineering. Screw threads of square, buttress and other shapes are also employed for special purposes.

The engineer's chief interest in this matter lies generally in the question of the fit between the threads of a bolt and its nut. If the nut is slack on the thread the strength of the connexion is greatly reduced and there is considerable risk, if too much force is used, that either one thread or the other will be stripped. If, on the other hand, the nut is tight, it is very difficult both to tighten up and to remove it, while if too much force is used the metal surfaces may seize, in which case it is generally impossible to effect removal of the nut without ruining the thread. Should a nut appear to be excessively tight, the threads should be inspected first to see if they are damaged, and if this is the case it is best to run a plug tap through the nut and to run the die lightly along the threads of the bolt until the nut can be turned with the fingers. Should suitable dies not be available the sharp edges of a triangular or similar file may be used to remove burrs or projections. Special attention is called for at the end of the bolt. Rusted nuts and bolts should be immersed in paraffin and retapped in the same way. For all purposes where maximum strength and grip are called for, the V-type screw is used.



SCREW THREAD. A, actual shape of screw thread on bolt; B, C, D and E, conventional methods of indicating external and internal threads on engineers' drawings.

Owing to the friction between the threads, the liability of the nut slackening back when subjected to vibration is much less than it is with square threads. The latter are also much weaker and are generally only used as a means of transmitting power without excessive friction, as, for example, on the leading screw and the cross and top slides of a lathe.

The dimensions of V-type screw threads as regards pitch and the angle of the V were first standardized about ninety years ago by Sir Joseph Whitworth, a pioneer of the engineering industry, and the standard Whitworth threads are extensively used in this country in all branches of engineering. For the requirements of motor car and aeronautical work it has been found necessary to use finer threads, known as the British Standard Fine (B.S.F.), which give greater grip and reduce the tendency to slacken back when subjected to vibration, while at the same time they do not cut so deeply into the bolt, and thus reduce the strength less.

Apart from the pitch of the threads, the British Standard Fine is identical with the Whitworth thread, the angle between the two sides of the V being 55 degrees. The pitch in every case depends upon the diameter of the bolt, and is smaller with bolts of small diameter.

A comparison between the two is given in tabular form below:

British Standard Whitworth				British Standard Fine		
Diameter of bolt in inches	No. of threads per in.	Diameter at bottom of thread	Diameter of tap drill	No. of threads per in.	Diameter at bottom of thread	Diameter of tap drill
		in.	in.		in.	in.
1/4	20	·1860	3/16	26	·2007	13/64
5/16	18	·2414	1/4	22	·2543	17/64
3/8	16	·2950	19/64	20	·3110	5/16
7/16	14	·3460	23/64	18	·3664	3/8
1/2	12	·3933	13/32	16	·4200	27/64
9/16	12	·4558	15/32	16	·4825	31/64
5/8	11	·5086	33/64	14	·5335	35/64
11/16	11	·5711	37/64	14	·5960	39/64
3/4	10	·6219	5/8	12	·6433	21/32
13/16	10	·6844	11/16	12	·7058	23/32
7/8	9	·7327	47/64	11	·7586	49/64
1	8	·8399	27/32	10	·8719	7/8

One-sixth of the full depth of the thread is rounded off both at the top and the

bottom to facilitate the cutting of the threads and to avoid a sharp, easily damaged edge.

Where threads are cut by the use of stocks and dies or taps, they will obviously be of the correct shape, but when the thread is cut in a lathe care must be taken to use a V-tool of the correct vertical angle and properly rounded at the end.

The diameter of a screw thread always means the outside diameter, and the hole drilled or bored in a nut or other part before tapping or screw cutting must therefore be of smaller diameter.

Where quick lengthwise motion of a nut is called for, double or even triple screw threads may be cut in the lathe. In the case of a double-screw thread, two separate helices or threads are cut, and the distance moved lengthwise of the nut for one rotation of the screw equals twice the distance between adjacent threads.

As mentioned previously, the B.S.F. thread is largely used in this country for general motor car work, but for small sizes, as used on instruments, an even finer standard is adopted, known as the British Association (B.A.). The B.A. thread is in practical use as a continuation of the B.S.F. thread for smaller sizes, being the standard screw gauge in this country as recognized by the Post Office Engineering Department, and approved by the British Standards Institution.

The British Standard Pipe thread (B.S.P.) is of the standard Whitworth V-form, but is of much smaller pitch than either the Whitworth or the B.S.F. standards for any given diameter. It is very widely used for conduits, pipes and tubes to avoid cutting too deeply into the thin material and also to give a powerful screwing-up effect with very little liability to slacken back.

Gauge diameters and number of threads are given in the table.

BRITISH STANDARD PIPE THREADS

Nominal bore of tube	Approximate outside diameter of black tube	Gauge diameter top of thread	Number of threads per inch
Ins.	Ins.	Ins.	
1/8	13/32	·383	28
1/4	17/32	·518	19
3/8	11/16	·656	19
1/2	27/32	·825	14
5/8	15/16	·902	14
3/4	1 1/16	1·041	14
7/8	1 7/32	1·189	14
1	1 11/32	1 309	11
1 1/4	1 11/16	1·650	11
1 1/2	1 29/32	1·882	11
1 3/4	2 5/32	2 116	11
2	2 3/8	2 347	11

Reference may also be made to a few different foreign standards. In America the Sellers thread takes the place of the Whitworth; the standard pitches adopted for the different diameters are similar, but the thread is flat at the top and the bottom instead of being rounded.

WHITWORTH'S STANDARD THREADS FOR PIPES

Nominal bore of pipe	Diam. of pipe	Diam. at bottom of thread	Threads per inch
1/8	·382	·336	28
1/4	·518	·451	19
3/8	·656	·589	19
1/2	·826	·734	14
5/8	·902	·811	14
3/4	1·04	·949	14
7/8	1·189	1·097	14
1	1·309	1·192	11
1 1/8	1·492	1·375	11
1 1/4	1·65	1·533	11
1 3/8	1 745	1·628	11
1 1/2	1 882	1·765	11
1 5/8	2·022	1·965	11
1 3/4	2·16	2 042	11
1 7/8	2·245	2·128	11
2	2·347	2·23	11

BRITISH ASSOCIATION (B.A.) SCREW THREADS

No.	Absolute dimensions in millimetres		Approximate number of threads per inch	Approx. dimensions in inches	
	Full diameter	Pitch		Full diameter	Pitch
25	0·25	0·070	362 8	0·010	0·0028
24	0·29	0·080	317·5	0·011	0·0031
23	0·33	0·09	282 2	0·013	0·0035
22	0·37	0·10	254	0·015	0·0039
21	0·42	0·11	230 9	0·017	0·0043
20	0·48	0·12	211 6	0 019	0·0047
19	0·54	0·14	181 4	0·021	0·0055
18	0·62	0·15	169 3	0·024	0·0059
17	0·70	0·17	149 4	0·028	0·0067
16	0·79	0·19	133 7	0·031	0·0075
*15	0·90	0·21	121 0	0·035	0·0083
14	1·0	0 23	110 4	0·039	0·0091
*13	1·2	0·25	101 6	0·047	0 0098
12	1·3	0·28	90 7	0·051	0·0110
*11	1·5	0·31	81 9	0·059	0·0122
10	1·7	0·35	72·6	0·067	0 0138
*9	1·9	0·39	65·1	0·075	0·0154
8	2·2	0·43	59·1	0 087	0·0169
7	2·5	0·48	52·9	0·098	0·0189
6	2·8	0·53	47·9	0·110	0·0209
*5	3·2	0·59	43·0	0·126	0·0232
4	3·6	0·66	38·5	0·142	0·0260
*3	4·1	0·73	34 8	0·161	0·0287
2	4·7	0·81	31·4	0·185	0·0319
*1	5·3	0·90	28·2	0·209	0·0354
0	6·0	1·00	25·4	0 236	0·0394

* The British Standards Institution recommended that for general use these sizes be dispensed with

SEALING BOX. Fig. 1 (left). Porcelain shank insulators are threaded over conductors which are then clamped in their respective terminals. Fig. 2. Presspahn diaphragms are placed in side entries and cover of box replaced. The box is then filled with hot compound.

W. T. Henley's Telegraph Co., Ltd.

Various metric standards are used in different European countries, diameters and pitch being both expressed in metric units.

Particulars regarding diameters, pitch and other characteristics of the various British and foreign screw threads will be found in engineering handbooks, but a selection of those commonly employed in electrical engineering work is given in the tables above. *See also* B.A. Screw Threads; Whitworth Thread.

SEALING BOX OR SEALING CHAMBER. A compound-filled cable box in which the end of a paper-insulated cable may be jointed to V.I.R. leads and hermetically sealed. The twin or concentric cable cores are bared, tinned, and connected to respective fuse terminals through porcelain shank insulators. Presspahn diaphragms are placed at the side entries and the cover of the sealing chamber affixed. Compound is then poured in as shown at Fig. 2, and a well-sealed fitting results. The V.I.R. leads are connected to the other fuse terminals and fuse covers replaced. *See* Cable Box; Joints and Jointing, *etc.*

SEARCH COIL. Name given to the rotating coil which moves between the fixed coils of a goniometer (*q.v.*). Also the moving coil of a ballistic galvanometer or other instrument to which an indicating device is joined, to show relative or absolute changes of flux in a circuit to which the instrument is connected. *See* Ballistic Method; Instruments.

SECONDARY CELL. A form of cell which has to be charged before electro-motive force is available at its terminals. There are only two types of secondary cell which have borne the tests of both time and practice. One is the lead-acid and the other is the alkaline; of which there are two forms—the Edison cell (*q.v.*) and the Jungner. The Edison cell has nickel positives and iron negatives, whilst the Jungner has nickel positives with mixed iron-cadmium negatives. The Drumm battery (*q.v.*) is a modification of the alkaline cell. *See* Accumulator; Battery; Charging and Charging Systems.

SECONDARY WINDING. The winding of a transformer which carries the transformed electrical energy, *i.e.* the winding not connected to the source of supply. *See* Circuit; Induction Coil, Primary Winding; Transformer.

SECTION BOX. Alternative name for Distributing Box (*q.v.*).

SECTION SWITCH. Enabling circuits or conductors to be split up into sections. Such a switch is usually incorporated on a bus-bar lay-out to enable faulty sections to be isolated for repair or inspection without interfering with the remaining sections. Similarly, the generating plant can be connected to different feeders or groups of feeders in the event of breakdown on one panel. *See* Bus-bars; Switchgear.

SEGMENT: COMMUTATOR. *See* Commutator; Dead Segment.

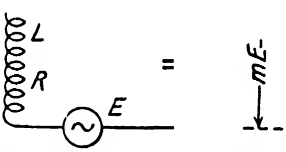
SELECTIVITY. In a radio receiver, selectivity implies the degree of freedom from interference by transmissions on wavelengths not far removed from that of the desired station, and where the unwanted stations have a signal strength at the receiving aerial comparable with or even greater than that of the desired transmission.

The true overall selectivity of a receiver can be defined as the ratio of the voltage produced at the grid of the detector at the

resonant frequency of the tuned circuits to that produced by another signal of equal strength and differing from resonance by a specified number of kilocycles per second, say 9 or 10 kc. per sec. There is, however, a more scientific method of expressing selectivity, this being considered below.

In the first instance, the overall selectivity of a receiver is proportional to the product of the selectivities of the individual tuned circuits, and therefore, in general, the greater the number of tuned circuits the greater is the degree of selectivity attainable. But it must be realized that selectivity does not infer freedom from "jamming," that is, interference by stations operating within the range of side-band frequencies of the desired station, but only the elimination of stations operating outside this range (*see* Side Bands).

As the overall selectivity depends on the individual tuned circuits, the selective properties of a simple tuned or resonant circuit will be considered first. Such a circuit consists of an inductance coil L shunted by a condenser C, as in Fig. 1.



SELECTIVITY. Fig. 1. Simple tuned circuit. At the resonant frequency the voltage developed across the circuit is greatest. The magnification m is $\frac{2\pi fL}{R}$

If a constant R.M.S. value of voltage of varying frequency is introduced into the closed circuit, either directly or by electro-magnetic induction, the resulting oscillating current will have a value always equal to the ratio of the voltage to the impedance of the circuit. Now as far as the oscillating current is concerned the closed circuit is a series one, and the total impedance is therefore given by the well-known formula:

$$Z=\sqrt{R^2+\left(2\pi fL-\frac{1}{2\pi fC}\right)^2}\text{ ohms}$$

where R ohms is the effective resistance of the circuit,

L henries is the inductance of the coil,

C farads is the capacity of the condenser, and

f is the frequency

Since the inductive reactance $2\pi fL$ is proportional, and the (negative) condensive reactance $1/2\pi fC$ is inversely proportional, to the frequency, it follows that

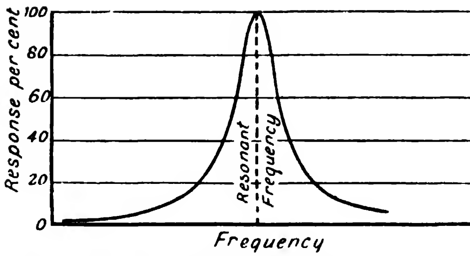


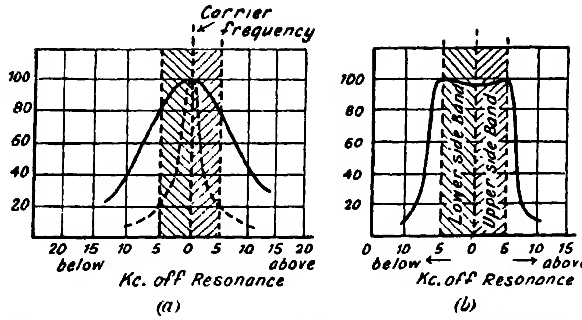
Fig. 2. General form of resonance curve for the simple tuned circuit of Fig. 1.

there must be one frequency for which these two neutralize each other completely, giving minimum impedance and maximum current. This is the resonant frequency, being $\frac{1}{2\pi\sqrt{LC}}$ cycles per second.

Resonance Curve. For frequencies above and below the resonant value the current falls off, and the response curve showing the relationship between frequency and current (or voltage developed across the coil as a result of the current) is of the form shown in Fig. 2, where the values are shown as percentages of the maximum for convenience. It can be shown that the ratio of the voltage developed across the circuit to that introduced into it at the resonant frequency is $\frac{2\pi fL}{R}$ or $\frac{1}{R}\sqrt{\frac{L}{C}}$, this being the voltage magnification m given by the tuned circuit. *This magnification is a direct measure of the selectivity of the circuit,* and it follows from this, as well as from observation, that the sharper the resonance peak the greater is the selectivity.

Reaction and Selectivity. The height of the resonance peak, and therefore the selectivity also, is inversely proportional to the effective H.F. resistance of the tuned circuit, and so efficient coils are a first essential. Reaction has the same effect as reducing the resistance of the tuned circuit (*see* Reaction), and by judicious use of reaction the selectivity can be greatly increased. By increasing the reaction and lowering the volume control, the selectivity can be increased without increasing the average volume, but, for reasons to be explained, this impairs the quality of reproduction.

Selectivity and Quality. Unfortunately quality of reproduction with ordinary tuned circuits is intimately associated with



SELECTIVITY. Fig. 3. (a) Showing how a sharply tuned circuit attenuates the higher modulating frequencies. (b) Resonance curve of a good band-pass filter.

the selectivity, an increase of selectivity inevitably resulting in attenuation of the higher note frequencies. The reason for this is due to the shape of the resonance curve in conjunction with the fact that a modulated wave is really equivalent to a number of unmodulated waves with frequencies falling within a band of values extending on either side of the carrier frequency (*q.v.*) by a number of cycles per second equal to the highest note frequency in the modulation (*see* Side Bands).

The relative effects for a highly selective and a flatly tuned circuit are clearly shown in Fig. 3 (*a*) where the side bands are indicated by the shaded areas, the highest note-frequency present being 5 kc. per second. The full-line resonance curve is for the relatively flatly tuned circuit, and it will be noted that at 5,000 cycles per second off resonance the response is 80 per cent. of the maximum, there being a 20 per cent. reduction of the 5,000 cycle note compared with those of the lowest frequencies. On the other hand, the sharply tuned circuit represented by the broken line curve gives only 20 per cent. response at 5 kc. off tune giving an 80 per cent. drop in strength of the 5,000 cycle note. In the former case the reduction is 1·9 decibels, and in the latter 14 decibels.

Band-Pass Tuning. In order that all modulation frequencies should be passed on at the same relative strength, the ideal resonance curve would have to be flat-topped with perpendicular sides. Band-pass filters for tuning purposes are aids to this end. By suitable design the overall resonance curve can be made reasonably flat on the top and yet have sufficiently steep sides to ensure the necessary selectivity. The type of resonance curve for a band-pass filter is shown at (*b*) in Fig. 3.

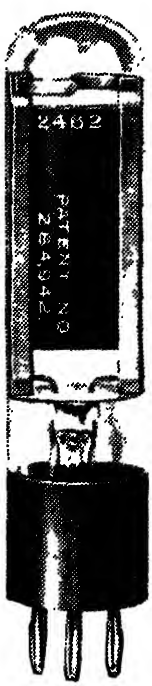
The principle of tone correction is frequently applied to compensate for the attenuation of the highest frequencies due to ordinary tuned circuits, but, although effective to some degree, it has the effect of reducing the apparent selectivity to some extent, and has the further disadvantage of lowering the general volume level. *See* Band-Pass Filter; Reaction; Tone Control and Correction.

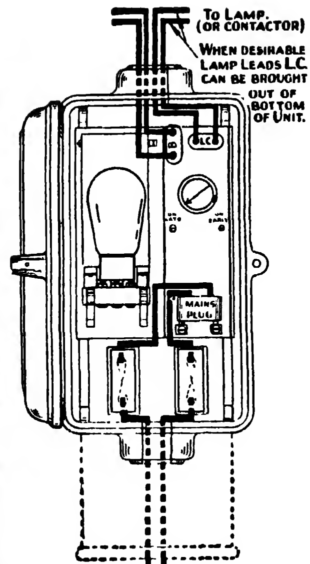
SELECTOR. That part of an automatic telephone equipment which is actuated by the dialling device at the transmitter to secure connexion with the subscriber with whom it is required to communicate. There are about twenty different kinds of selectors used for the various operations of connecting one line with another, but information relative to the basic principles upon which they operate will be found under the heading Automatic Telephony.

There are also selectors in automatic sub-station equipment. The feeler switches (*q.v.*) operate through selector mechanism and will not close if the selectors reject, for some reason, the closing of a circuit.

SELENIUM CELL. A light-sensitive device utilizing the property of selenium that its resistance becomes less when light falls upon it. Also called the selenium bridge. Selenium is a non-metallic element, chemically resembling sulphur and tellurium, and occurs in several allotropic forms varying in specific gravity from 4·3 to 4·8. Melting point 217° C.; boiling point 690° C.; resistivity 60,000 ohms at 0° C.; dielectric constant 6·1 to 7·4. Resistivity in darkness may be anything from 5 to 200 times resistivity under exposure to light, depending on intensity; sensitivity is greater at low light intensity than at high. There is a slight time lag in response, but it is insufficient to affect the majority of applications.

The light sensitive property of selenium is developed by annealing at a temperature approaching its fusing point. The operating characteristics of the cell depend to a considerable extent on the care and attention taken in annealing. In the con-





SELENIUM CELL. Fig. 1. The Radiovisor Bridge, consisting of a selenium film spread on insulating base, with gold electrodes, sealed in glass container. Fig. 2. Connexions of bridge for lighting control.

Radiovisor Parent, Ltd

struction of the cell, selenium is deposited on a glass plate and divided by thin lines to produce a long zig-zag strip. Electrodes are fitted to each end, the whole being suitably mounted in an evacuated glass tube with external contacts, or terminal pins. In practical applications thermionic valves, or equivalent means, are employed to amplify the variations in current originating in the cell, to the degree required to actuate an associated relay or switching apparatus.

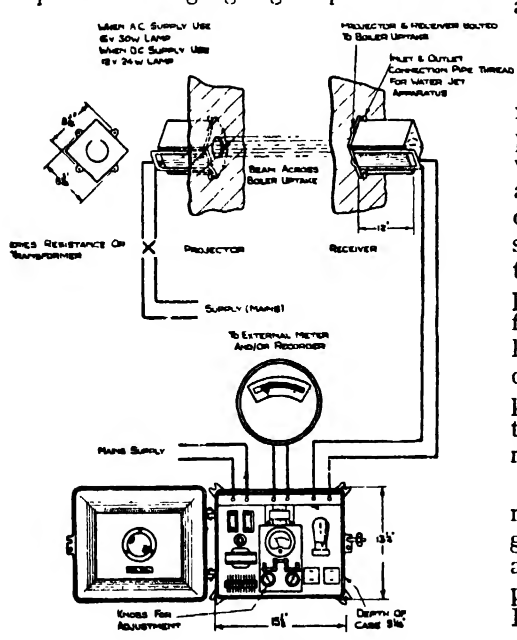


Fig. 3. Pictorial diagram of control box, receiver and projector employed in the Radiovisor industrial smoke indicator.

Applications. The purposes to which selenium cells have been applied in industrial and commercial service are innumerable. They include switching street lights on and off automatically as daylight fades and increases; opening doors as one approaches to walk through; timing races; detection of fires by the presence of smoke; counting articles passing a given point on a conveyor line, etc.; protecting machine operators; and actuating burglar alarms by "invisible" rays. Television and talkie systems have also been developed using selenium cells, though the photo-electric cell (*q.v.*) is normally used for these purposes nowadays.

The equipment associated with a cell varies with the function to be fulfilled. For street lighting control the usual arrangement is as follows. A fixed resistance is connected in series with the cell and in circuit with a thermionic amplifier valve. A negative potential is applied to the valve grid, such that when the cell resistance is high (during darkness) the passage of anode current is prevented, while with low cell resistance (in daylight) anode current flows. The anode current operates a switch relay, or contactor switch, in a secondary circuit to switch out the lights; the switch relay is permanently polarized and with no anode current flowing the switch closes and puts the lights "on." The like purpose is fulfilled on D.C. supply utilizing a sensitive polarized relay in substitution of the thermionic valve, and a mercury switch relay in the lamp circuit.

For burglar alarms, smoke indicators, race timing, counting devices, etc., the general arrangements are similar to the above, except that a beam of light from a projector lamp is focused on to the cell. Interruption of the light beam by an opaque body causes the current variations in the primary circuit which are utilized to actuate the appropriate devices. In

burglar alarms an "invisible" ray is utilized, interruption of which causes the controlled equipment to function as with a visible light beam. The alarm circuit can be arranged, if desired, to ring up the nearest police station and indicate where the robbery is taking place, without in any way rousing the suspicions of the thief. *See* Caesium; Light Relay; Photo-electric Cell; Radiovisor; Television.

SELF-CAPACITY. The inherent capacity of a circuit or part of a circuit. Practically all electrical circuits possess capacity. Thus in an electric cable, the conductor, *i.e.* the stranded wire, forms one plate of a condenser, the insulation forms the dielectric, and the earth in which the cable is laid, or the outer lead casing by which it is protected, forms the other plate of the condenser. Two wires which are close to one another have a definite capacity, the air or intervening medium acting as the dielectric.

In a coil, there is a capacity effect between every adjacent turn, and the whole coil has a definite self-capacity. A suspended wire, too, has a capacity to earth, the latter acting as one plate of a condenser, the wire as the other, and the intervening air as the dielectric.

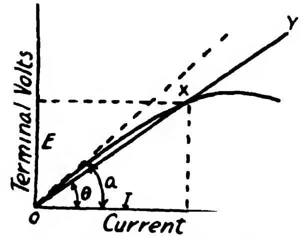
Self-capacity in radio circuits, and especially in coils, is to be avoided wherever possible. Wires should cross as nearly as possible at right angles, and the farther apart the better. *See* Capacity.

SELF-INDUCTION. As explained under the heading Mutual Induction, a conductor carrying a current of varying value is surrounded by a magnetic field which varies with the current. Conversely, if a conductor forming part of a closed circuit is surrounded by a varying magnetic field a current is induced in it. The consequence of these two phenomena is that when a current flowing in a conductor varies, the varying field it sets up in turn generates a second current in the conductor. This phenomenon is known as self-induction. The direction of the second current is important. When the first one is growing, the second one is in the opposite direction. It, therefore, opposes the first and makes it grow more slowly. When the first is dwindling the second is in the same direction and makes it tend to keep on. Thus the effect of self-induction is to oppose any change in the current.

The property of the circuit on which the phenomena of self-induction depends is called its "electro-magnetic induction" or "coefficient of self-induction." A circuit for which this is large is often spoken of as "highly inductive." This coefficient of self-induction is greater for a coil than for a single conductor because each turn makes a contribution to the magnetic field created by a current. It is also greater for a circuit in the vicinity of magnetic iron. A coil wound on a soft iron core has, therefore, a high coefficient of self-induction. A field magnet is an example. If a switch in this is suddenly opened the effect of self-induction is to cause the current to try to flow on. A large voltage is built up which can arc across a considerable distance. For this reason it is dangerous to break the field circuit of a machine suddenly. It is usual to provide special switches for the purpose fitted with discharge resistances (*q.v.*), which allow the current to dwindle slowly.

When an alternating current is passed through an inductive circuit the effect of its coefficient of self-induction is to oppose the current during each quarter cycle when it is growing and to cause it to flow on during each quarter cycle when it is dwindling. The result is that the current does not build up to the same maximum value as it would in a non-inductive circuit and, moreover, that it reaches that value later. It is said to be displaced. The effect of the inductance which reduces the current is called the reactance (*q.v.*) of the circuit. *See* Inductance; Induction.

SERIES CHARACTERISTIC. The load characteristic of a series wound dynamo showing the relation between the terminal volts and current, rises sharply at first, becoming flatter and curving over as the current increases. At any point X on the load characteristic shown in the diagram, the voltage being E, and the current I, the load resistance is given by



SERIES CHARACTERISTIC. OZ represents critical resistance value. OXY is resistance line of load.

E/I = tan θ where θ is the angle of slope of the curve. OXY is known as the resistance line of the load. OZ, the tangent to the curve, represents the limiting resistance line or critical value of load resistance. At this value, unless the speed be increased, the machine will not excite. Thus for all values of resistance greater than that represented by OZ there will be no generation, and for all values less than tan α the machine will excite.

SERIES COIL. Name given to that part of a field winding of a compound-wound machine which is in series with the armature. From the series characteristic (*q.v.*), it is seen that the effect of the series coil is to increase the terminal volts with increase in field current. The series field winding carries the main current and on full load the series ampère-turns have normal value for efficient operation, whilst on no-load the series coil carries no field current and has no effect on terminal volts.

This is the reverse effect from that met with in the shunt (*q.v.*) coil, where the terminal volts fall off with the load current. By combining the two effects, therefore, we should expect to obtain steady voltage at the terminals for all conditions of load current from no-load to full load. This is the underlying principle of compound winding (*q.v.*).

The term is also applied to the winding of a dynamometer wattmeter or similar instrument which carries the main current. *See* Current Transformer; Field Coil; Instruments; Wattmeter.

SERIES CONDUCTION MOTOR. This is a term used to describe A.C. commutator motors in which the stator and rotor are connected in series, and the same current passes through both. Motors of this type can be designed for operation on any particular number of phases, but the most common are single- and three-phase. The single-phase motor is connected in the same way as the D.C. machine, but modifications are made in the connexions of the compensating winding. In some cases this is also connected in series, but in others it is short-circuited on itself, and the neutralizing current (so called because it neutralizes the effects of armature reaction) is induced by transformer action from the armature. This type of neutralized series motor is used extensively for single-phase traction work operating at pressures up to 500 volts. In order to improve commutation on these motors, which have an output up to about 700 h.p., the frequency is kept as low as possible, 16$\frac{2}{3}$ to 25 cycles per second. The three-phase series motor is more used on hoists, cranes, lifts and similar loads, and in this case the stator is wound in the same way as an induction motor, one end of each phase being connected to the supply and the other ends connected one to each of three sets of equally spaced brushes on the commutator.

Speed control in either single- or three-phase motors can be obtained either by altering the brush position or by means of a tapped transformer. The former method is objectionable on the grounds that it produces a low power factor at low speeds. *See* Commutator Motor, Series Motor.

SERIES CONNEXION. Two or more conductors are connected in series when they are so joined that a current can flow from one to the next without being increased or decreased in amount. If a current passes through several resistances as shown in Fig. 1, the resistances are said to be joined in series. Joining resistances in this way is equivalent to making a resistance equal to the sum of the separate resistances. If R is the total resistance, then this fact may be expressed by the equation $R = R_1 + R_2 + R_3$.

Fig. 1

Fig 2

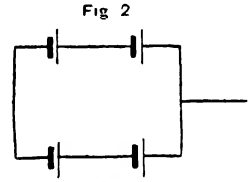


Fig. 3

SERIES CONNEXION. Fig. 1. Group of resistances series. Fig. 2. Cells in series. Fig. 3. Cells in series-parallel connexion.

Fig. 2 shows how cells are joined in series to form a battery, the negative element of one cell being joined to the positive of the next and so on.

Fig. 3 shows a combination of these two methods, and is known as a series-parallel arrangement. When cells are joined in series the total E.M.F. is equal to the sum of the separate E.M.F.'s, and the total internal resistance of the battery is equal

to the sum of the separate internal resistances of each cell. In a parallel arrangement the total E.M.F. is the E.M.F. of one cell, and the total internal resistance equals internal resistance of one cell divided by the number in parallel.

By a series arrangement a greater E.M.F. is obtained and by a parallel arrangement a greater current.

The capacity of a number of condensers arranged in series is given by the reciprocal of the sum of the reciprocals of the separate capacities. *See* Battery; Capacity; Parallel Connexion; Resistance.

SERIES DISTRIBUTION. *See* Thury System.

SERIES EXCITATION. The field winding is connected in series with the load and therefore carries the main current. On full load the field ampère-turns have normal value for efficient operation, whilst on no-load there is no field current and consequently no generated E.M.F. *See also* Series Characteristic; Series Coil, *etc.*

SERIES FIELD. The part of the flux in a compound-wound machine produced by the series winding is referred to as the series field. Speed control may be effected by variation of this flux caused either by shunting the series winding with a resistance, or by cutting out some of the series turns. *See* Field Regulator; Series-Parallel Control, *etc.*

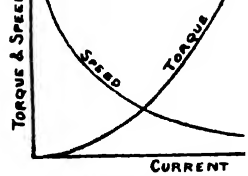
SERIES GENERATOR. In this class of dynamo electric machinery the field coils, consisting of a small number of turns of comparatively heavy gauge, are connected in series with the armature, and carry the whole or a predetermined portion of the total current. At one time series generators were used as constant current machines for series arc-lighting, but with the passing of this system of lighting they have fallen into disuse, as the manner in which their terminal voltage varies with current finds little or no commercial application. When increased external current is taken from a series generator the terminal voltage at first increases rapidly, but after a certain point, owing to the voltage drop in the armature and field windings, and to the effect of armature reaction, the voltage begins to decrease. *See* Compound Winding; Field Winding; Generator; Thury System.

SERIES INDUCTION-CONDUCTION MOTOR. Instead of connecting the stator and armature directly in series with the mains (as described under Series Conduction Motor), it is sometimes more convenient to feed the rotor through a series transformer, and this gives rise to the above term. In this system a pressure considerably lower than the supply voltage is applied to the armature; this lowers the cost of insulation, increases reliability, and improves commutation.

The characteristics of the machine are, of course, the same as those of the simple series motor, as the armature current is always a fixed multiple of the stator current. By using a tapped transformer, economical speed control can be obtained; as for the same line current taken a lower tapping would produce lower armature voltage but higher current. The lower voltage would give decreased speed, and the higher current increased torque.

This system is applicable to systems of any number of phases, but its chief advantage is in three-phase working, as it is possible to change the supply to the armature to three, six, nine or twelve phases by means of the transformer. The increased number of phases requires a corresponding increase in the number of brush arms, and this often enables a better proportioned commutator to be used, and greatly improves commutation. *See* Commutator Motor.

SERIES MOTOR. A series motor is one in which the field is excited by the same current that flows through the armature. This means that the field windings must be wound to carry the full-load current of the machine, although only a few turns are necessary. In multi-polar machines, the windings on the poles may be connected in a series-parallel arrangement so that only a part of the full load current passes through each, so that the field coils can be wound with a smaller conductor.



SERIES MOTOR. Mechanical characteristics of series motor showing variation in torque and speed with increase in armature current.

When the current taken by the machine is high, the field is strong, so producing a

large torque, which is dependent on the product of armature current and field strength. With a strong field the speed of rotation is low, as the speed is a function of the back E.M.F. generated in the armature, and this depends on the product of field strength and speed, and must always be approximately equal to the voltage applied to the machine. *See* Motor; Thury System.

As the load is taken off the motor (*i.e.* the torque necessary is decreased), the current falls, and due to the weakening of the field, the speed must increase. The characteristics of the machine are therefore of the form shown, so that if the load is taken off, the speed of the machine tends to become infinite, *i.e.* it "runs away." This would result in the bursting of the armature due to the centrifugal forces set up, so the motor is usually coupled to its load in such a way that the coupling cannot come adrift, as, for example, by means of gears. It must never be connected by a belt which is liable to break. In a case where the load is liable to come off, a minimum current circuit breaker or its equivalent should be used.

Applications. The chief application of the series motor is to electric traction, for which purpose its characteristics are particularly suited. Thus it can be designed to have high starting torque, a feature necessary for the rapid starting of trains, while a small decrease in speed produces a comparatively large increase in torque, thus enabling speed to be maintained on hills. The control of the motor at starting and in varying speed can be made very economical where more than one motor is used, as is usually the case in traction service. At starting the motors are connected in series with one another, and when the starting resistance is cut out, the motors are then connected individually to the supply, first of all with resistance in series, this again being cut out. Speed control is usually effected by means of a diverter resistance in the field circuit. This resistance is inserted in parallel with the field coil, so that part of the current is by-passed from this and the field is weakened.

When series motors are used as generators for braking, it is necessary to reverse the field connexions. The reason for this is that in changing from motoring to generating, the current in the armature must reverse, and the current through the field coils would be in the wrong direction to allow the field to build up.

Most electrically driven road vehicles are fitted with series motors, although some lighter types of battery vehicles have shunt or compound motors. The driving motors of petrol- or oil-electric vehicles are series machines, but here starting and speed control are obtained by varying the voltage generated, and not by means of resistance and a diverter respectively.

Other applications are to cranes and hoists, where a fast lift on light load enables considerable time to be saved.

A.C. Series Motor. If the voltage applied to a D.C. series motor is reversed, the direction of rotation is unchanged, so that with an alternating voltage applied, the reversal of current in each cycle will not cause a reversal of torque, which would result in the machine locking. As the field is excited by the armature current, the field and current are always in phase, and the machine will operate satisfactorily. As the flux in all parts of the magnetic circuit is alternating, the yoke must be laminated as well as the armature. Even so the iron losses are considerably higher than in a D.C. machine of the same rating, and as the peak value of the voltage is $\sqrt{2}$ times the R.M.S. rating, the iron section is also larger. This means that the A.C. machine will be larger and more expensive than a D.C. machine of the same rating.

The characteristics of the two machines can be made almost identical, but the simple A.C. series motor is not much used in practice. Another difference between the D.C. and A.C. machines is that in the latter the poles do not project from the yoke, but the field winding is placed in slots in the same way that the stator of an induction motor is wound.

One of the chief troubles associated with the A.C. commutator motor in its earlier development was that of armature reaction (*q.v.*), which is much more troublesome to overcome so far as its effects on commutation are concerned than in the D.C. case. It is overcome in modern machines by introducing a compensating

winding (*q.v.*) to neutralize the armature reaction over the whole armature, as well as providing interpoles of the ordinary type. The name series motor is given to A.C. machines which are not series connected, but which have the characteristics of a series motor.

The advantage of the series motor over the induction motor is that it has a high power factor (near unity) and a very high starting torque, while speed control can be carried out simply and economically. Its applications are the same as those of the D.C. machine, and it is standard practice on the Continent to use high-voltage A.C. on the main electrified railway lines, this being stepped down on the locomotive and supplied to the series motors (*see* Traction).

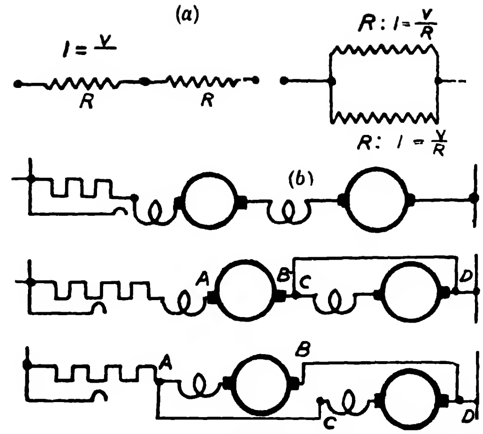
A.C. series motors are built for outputs up to 1,000 h.p., but above this the usual practice is to connect them in cascade with an induction motor, and this system is in extensive use for rolling-mill drives. The commutator motor is fed from the rotor of the induction motor, and therefore its supply frequency is low. *See* Booster; Commutator Motor; Compound Generator.

SERIES-MULTIPLE CONNEXION. Alternative name for series-parallel connexion, multiple being the American synonym for parallel.

Applied to machines, lamps or other apparatus connected alternatively in series and in parallel, or to machines or apparatus connected in series groups in parallel with one another. *See* Parallel Connexion; Series Connexion; Shunt Connexion, *etc.*

SERIES-PARALLEL BATTERY CONTROL. A method of controlling the speed of battery-operated vehicles by connecting sections of the battery in series or parallel as desired, and thus regulating the voltage applied to the motor, and consequently its speed.

SERIES-PARALLEL CONTROL. A method of variable voltage control. It will be readily seen from Fig. 1 that when this system of control is applied to the simple case of two similar pieces of apparatus, the voltage across each when connected in series is one half that when parallel connexion is employed.



SERIES-PARALLEL CONTROL. Fig. 1 (*a*) In series, voltage drop across each section, is half the applied voltage. In parallel, there is the full voltage across each section. (*b*) Steps in transition from series to parallel control.

This method may be employed for the control of variable speed motors, in which case two motors, which must have similar characteristics, are first connected in series, usually with a starting resistance, or rheostat, in circuit, and accelerated to half speed, after which the two motors are connected in parallel, usually, as before, in series with a starting resistance, and accelerated to full speed. Series-parallel control is also applied to other types of electrical apparatus, such as electric lamps, when the alternative use of "dimmed" and "full" lights is required, either as a necessity or convenience; namely, in hospitals, hotels, railway carriages, and automobiles; to heating and cooking circuits, when low and full heat are required from the elements—low when connected in series, full in parallel, and in the control of radio and other electric circuits.

Series-parallel motor control is employed for the control of the motor equipment of D.C. traction (*q.v.*) systems almost universally. It is also used on A.C. traction systems, but to nothing like the same extent. By this method full and half speed may be obtained, without rheostatic losses. Other speeds may be obtained by introducing resistances in series with the motors by drum controllers or contactor gear, or by field control, or by both methods. To secure the utmost benefit from this system the acceleration should be smooth and the torque uninterrupted; at the

transition stage from series to parallel. These conditions are difficult to attain.

Methods of Changing Connexions. Four methods of changing over the connexions are recognized. One of these involves the use of a separate change-over switch, and is clumsy, and the other three are known as open circuit, shunt (or short circuit), and bridge methods of transition respectively. In the open circuit method, when the motors have been accelerated up to half speed and all the resistance cut out, both motors are disconnected from the supply, and then re-connected in parallel. During the transition there is no torque, consequently on an up-grade difficulties are likely to arise when attempting to pass this point, and there is also the possibility of heavy arcing. Consequently, this method is only employed for small motors where a short idle period is not likely to prove disastrous.

In the second method, when the series resistance has been cut out, one of the motors is short-circuited, leaving the other to provide the torque; a section of the resistance being reintroduced at the same time to prevent excessive voltage rise on the active motor during the period of transition; the other, being in series with its fellow, is not liable to damage. Finally, the temporarily inactive motor is re-connected in parallel across the other by disconnecting its inner terminal and reconnecting to the terminal of the other, as shown in Fig. 2. For hand control, this is the method most widely adopted.

In the bridge method, two starting or regulating resistances are employed, and the connexions are similar to those of the Wheatstone bridge, the bridge connexion being formed just before transition. Provided that the voltage across each section is the same, that is, the motors are running at such speed that their back E.M.F. is equal to the potential drop in the resistors A and B, they are at the same potential and so no current (with consequent arcing) has to be interrupted. The chief difficulty is in gauging the correct speed of the motors at which to effect the change-over. Hence this method finds its chief application in indirect control, that is by contactors, for railway traction.

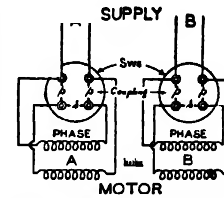
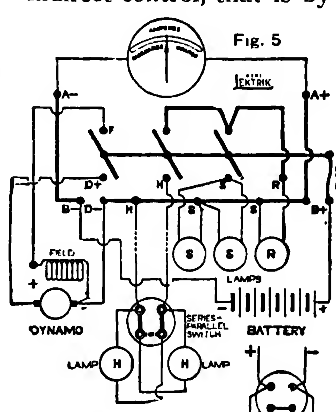


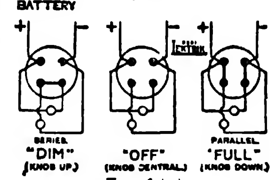
Fig. 3. Series-parallel field control for motor. *A. P. Lundberg & Sons*

The switching in this and other methods of series-parallel motor control is effected by special controllers (*see* Drum Controller). A method of controlling A.C. motors by a simple series-parallel switch is shown in Fig. 3, the phases of the stator winding being specially wound in two parts.

For the control of lighting circuits a series-parallel tumbler switch may be employed. Fig. 4(*a*) shows a switch of this type applied to the control of two lights.

Similar connexions may be employed for heating circuits. Although the connexions shown in Fig. 4(*a*) are the most usual, when lamps, heaters, fans, and small motors, etc., are to be connected by a





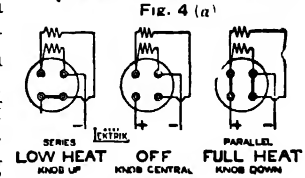
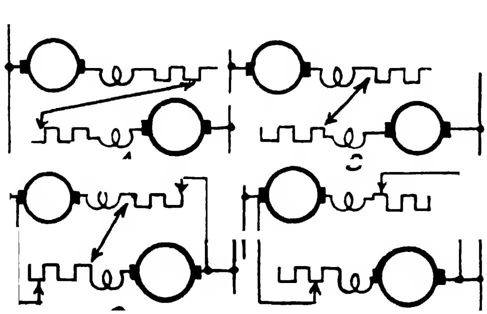


Fig. 4. (*a*) and (*b*) Two methods of connexion for lighting and heating control. Fig. 5. Automobile lighting circuit diagram employing series-parallel system. *A. P. Lundberg & Sons*



SERIES-PARALLEL CONTROL. Fig. 2 (a) Series connexion, first position; (b) series connexion, final position; (c) transition period; (d) parallel connexion, first position.

series-parallel switch; those shown in Fig. 4(*b*) are simpler and cheaper, requiring only a three-pin plug connector.

Series-parallel control may be applied to automobile lighting, and Fig. 5 shows one method by which the head lamps of a car can be dimmed. *See* Controller; Traction.

SERIES-PARALLEL WINDING. Any winding which consists of a parallel section connected in series with another, but applied more specially to a form of armature winding for D.C. machines, which is also known as a multiplex wave winding (*see* Wave Winding). By the suitable choice of the number of winding elements and pitch, the number of parallel paths may be made equal to any whole number desired. This method, like that of the multiplex lap winding, lends itself to large outputs at low voltages, but it is distinguished from this winding inasmuch as the number of armature paths bears no relation to the number of poles.

Windings of this type are usually avoided by designers, though successful machines of high capacity have been manufactured on the Continent (the original patent for this type of winding being held by E. Arnold, and exploited by Oerlikon), and by at least one reputable manufacturer in this country. They do not possess great advantages over the more simple windings; since the theory underlying them is more complicated and extreme care is necessary both in design and manufacture if symmetrical windings and good commutation are to be ensured.

SERIES WINDING. A winding associated with a magnetic circuit, through which the whole or a certain proportion of the line current flows. The magnetic flux set up by this type of winding varies in proportion to the line current, and not, as in the case of shunt windings, directly to variations in line voltage.

Compared with shunt windings, series windings have fewer turns, and the conductors are of heavier gauge, both of which differences are due to the heavier currents carried—fewer turns being required because the magnetic effect of a winding is proportional to the product of the current and the number of turns.

Series windings may be employed—alone or in conjunction with shunt windings—to produce a resultant magnetic effect which is proportional to both current and voltage variations. Apart from the use of these windings for certain classes of electric motors and generators (*see* Series Motors), the main use of series windings is for current limiting devices (excluding here the solenoids employed with push-button and similar controls and instrument transformers). A simple example of this application is the overload coil on the starters employed for D.C. shunt or compound motors. This is connected in series with the armature, and should the armature current become excessive through overloading or any other cause, the overload coil operates a plunger or arm, which by short-circuiting a pair of contacts releases the starter-arm. Similar overload coils are employed for tripping circuit breakers. For A.C. circuits the trip coil is usually connected to the secondary of a current or series transformer.

As explained elsewhere, when starting motors it is usual to limit the current by reducing the voltage applied to the armature, which in the case of D.C. (and some A.C.) machines is achieved by connecting a number of resistances in series with the armature, which are gradually cut out as the speed of the machine rises. This gradual cutting out of resistances may be done by hand, in which case the starting handle is moved from stud to stud as the current falls to a certain minimum value, or by contactor gear employing a counter-E.M.F. starter.

Series Lock-Out Contactor. This may also be achieved by what is in effect the most fundamental form of control, a series lock-out contactor. In this latter, a number of series coils carrying the main motor current are employed and the contactors are kept open until the current has fallen to a predetermined value.

Two types exist, the single and the double coil. In the first, the contactor arm, which is of magnetic material, is controlled by two magnetic circuits but only one coil. The first magnetic circuit is entirely of iron, but a section of this is restricted so that it easily becomes saturated; the other is of ample cross-section but contains an air-gap. When the current exceeds a certain value the

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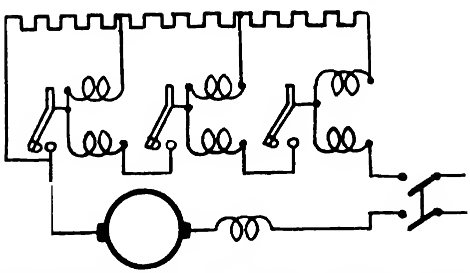


SERIES WINDING. Series coils in double-coil series lock-out contactor.

effect of the latter circuit predominates and holds the contactor open; as the current falls, the other circuit becomes the more effective, because the restricted portion is no longer saturated and the air-gap now offers the greater resistance. Hence the contactor closes.

The double-coil type, the circuit of which is shown in the figure, is similar in action but is more positive.

A further use for series coils is in the protection of feeders, both against overload and leakage, and for the protection of transformers, alternators, and similar apparatus. Well-known systems of this type are the Merz-Price and the Beard-Hunter. *See* Protective Devices.

SERVICE CABLE OR SERVICE MAIN. The cable that joins the consumer to the supply mains. Generally, the supply mains run through the street, whilst the service main is joined thereto and runs into the house, being joined to the consumer's installation at the main switch, *via* supply fuses and meters. Connecting up to the supply can only be arranged after the consumer's installation is completed and has passed the insulation test in accordance with Rule 1104 of the Regulations for the Electrical Equipment of Buildings of The Institution of Electrical Engineers. In these regulations there is provision for the satisfactory testing of the conductors to earth, the method in which this testing shall be carried out (*i.e.* with lamps in place or not, depending upon the system of wiring), and the insulation of conductors from frameworks being specified. Continuity of sheathings is also to be tested, and according to the I.E.E. rules provision for proper earthing must be made in accordance with Rules 1109 and 1110 for the testing of earthing. *See* Connexions; Fault (Cables).

SERVING. The application of a protective covering to any cable or rope for the purpose of preventing it from fraying or receiving damage due to abrasion or impact. Sheathed and armoured cables are often served for this purpose, and the covering used may be jute or fabric tape. *See* Cable.

SERVO-MOTOR. A mechanism for converting a small movement into one of greater amplitude or with greater force to effect it. Extensively employed in all branches of engineering as, for instance, the dual oil-filled piston arrangement adopted for turbo-generator steam control, the linked motions employed for brake operations in traction, hydraulic lifting jacks, and many similar devices. Small electric motors, known as pilots, are also used for this purpose, generally to actuate auxiliary apparatus in connexion with larger motors.

SEWING MACHINES. The application of electricity to sewing machines lies in connecting an electric motor to existing mechanism formerly hand, or otherwise mechanically, operated. There are three ways in which electric motor drive is applied: by transmission drive; direct, or by combination declutching for electric or hand drive. This service is one of the few in which the application of electricity seems to have done little to increase the uses to which previously existing machinery is put. Nevertheless, electric drive allows considerable economy in time of sewing and in ease of manipulation for domestic purposes, and greatly increased output in tailoring and other industrial forms.

SHADE. A simple electric light fitting for direct lighting installations, intended to prevent an observer from being subjected to direct glare from the lamp.

Silk and parchment shades for pendant fittings, and pedestal and table lamps are still popular for domestic lighting, but have little to recommend them except their pleasing, and in some cases homely, appearance. Usually the light distribution from such shades is poor, and a considerable proportion of the light emitted by the lamp or lamps is absorbed by the material of the shade. By replacing these shades by modern fittings considerable economies can usually be effected.

The conical shade which was at one time very popular for industrial and commercial installations, was designed for the now almost obsolete carbon filament lamp. Much of the lamp is exposed to view, and with modern lamps of high intrinsic brilliancy the resulting glare is considerable. Moreover, shades of this type do not distribute the light in the most effective manner. In spite of their low initial cost it is cheaper in the long run to employ modern reflectors.

For large industrial and commercial installations, where no decorative effect is required, well-placed R.L.M. reflectors are to be preferred to shades, a smaller number being required. Where this type of reflector is unsuitable various other dispersive reflectors are available (*see* Lighting Fittings).

There is no justification for the continued use of conical shades even for small installations, where first cost may assume considerable importance. The Coolicon shade is extremely cheap, and is the modern answer to the conical shade. It is well within the weight limits recommended for cord-grip suspension, and can be used with bakelite holder and skirts, allows the correct proportion of light for ceiling illumination, and avoids excessive heating of the lamp holder.

Porcelain enamelled and aluminium parabolic reflector bowl shades prevent direct glare, but are not as a rule sufficiently dispersive to prevent reflected glare from polished surfaces. Their chief uses are for supplemental lighting to assist a general illumination of diffused character. The same remarks apply to mirrored-glass shades.

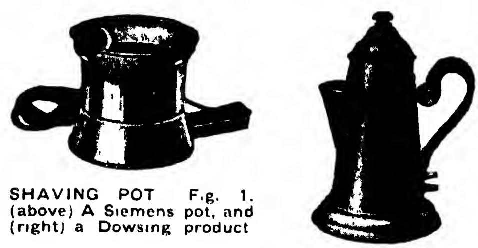
Prismatic glass shades utilize light as efficiently as the best vitreous enamelled metal reflectors, but are not so dispersive. They are considerably less formal and may be used in offices, shops, and for home lighting, when more elaborate fittings are considered to be out of the question. They do not obviate reflected glare, and when a simple fitting is required, which will reduce both direct and reflected glare, an opal glass reflector with a deep bowl and a frosted lamp is recommended. *See* Illumination; Lighting; Lighting Fittings; Reflector.

SHADE CARRIER RING. The shade carrier or gallery is usually secured to the lamp holder by means of a screwed ring or similar attachment. *See* Gallery.

SHADED POLE. *See* Shielded Pole.

SHAFT CURRENTS. In addition to eddy current losses in the armature core of rotating machinery, stray currents are set up in the shaft and bearings. These are liable to set up electrolytic action, causing corrosion of the journals and bearings in addition to the energy loss they occasion. They are usually not serious enough to warrant any extra expenditure on overcoming these defects, however, and for all practical purposes may be neglected.

SHAVING POT, ELECTRIC. A small container or jug in which water for shaving can be heated up by electric elements fitted to the pot. They are made in various shapes and sizes, and commonly have service convenience features, such as



SHAVING POT Fig. 1. (above) A Siemens pot, and (right) a Dowsing product

a ledge for supporting the brush or soap. The interior is usually tinned copper and the outside polished copper, nickel or silver plated. Elements are mostly of the mica wound type, clamped to the underside of the bottom. Loadings are of the order of 200 watts, $\frac{1}{2}$ pint, and 300 watts, $\frac{3}{4}$ pint capacity. Water is raised to, say 180° F., in three to four minutes; consumption about $\frac{1}{2}$–$\frac{3}{4}$ unit per week.

Shaving pots are normally supplied with appliance connector, two yards of flexible and bayonet adaptor for connecting to a lamp holder; or possibly a two-pin wall plug may be provided. In these circumstances there is no provision for "earthing" the pot.

It is therefore inadvisable to use them in a bathroom or in the vicinity of earthed metal, as in the event of the metal pot becoming alive a dangerous shock might be experienced.

Provision should be made for earth protection by 3-pin contacts and flexible,

or the pot should be heated up away from the bathroom and disconnected from the supply circuit before being taken into the bathroom for use.

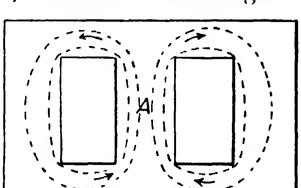
SHEATHING (Cable, Cab-Tire, Lead, and Tough Rubber). Cable sheathing is a generic term employed for the outer protective covering on a cable, which may be of hard rubber, known as Cab-Tire or Tough Rubber Sheathing, or of lead alloy.

For lighting circuits, in normal situations V.I.R. cable (*q.v.*), braided and run in conduit, is commonly employed. In damp situations or where surface wiring is adopted, however, either lead covering, or compound rubber, impervious to mechanical or chemical damage, must be used.

With impregnated, paper-insulated power cables, lead sheathing is always employed, but for small-power circuits, such as those met with in domestic and industrial installations, the flexibility and ease of jointing of the T.R.S. cable are greatly in its favour. Its wearing qualities and resistance to corrosion attain a high standard, and have led to its application for trailing cables in mines, cinema studios, and many other similar purposes.

See also the various wiring systems discussed under their own headings throughout this work; Armoured Cable; Cable; Cab-Tire Sheathing; Tough Rubber Sheathing; V.I.R., *etc.*; *and under* Wiring.

SHELL TYPE TRANSFORMER. One of the two classifications into which modern transformers fall; the other class being the core type. The shell type is so called because it has its core forming a shell round the windings, *i.e.* the core totally encloses them, as indicated in the figure. The magnetic circuit of this transformer is two paths in parallel.



SHELL TYPE TRANSFORMER. The magnetic circuit. Windings are on central limb A.

The difference between this type of transformer and the core type is chiefly in manufacturing detail as the efficiency—taken on the average—is much the same in both cases. This type does not, however, find such favour in modern practice as the core type.

SHIELDED POLE. Also known as shaded pole. A method whereby a phase difference in the alternating magnetic fluxes in two pole pieces, excited by the same winding, is obtained by a copper ring or band encircling one of the poles. The phase displacement of the flux in the shaded or shielded pole is due to the magnetic effect of the currents induced in the ring or band. The shielded pole construction is used in over-current relays, and in small single-phase induction motors. In its latter application it does not lead to a very efficient design, but it has the merit of great simplicity, in that a single stator winding only is required. *See* Inductance; Motor.

SHIELDING. The protection of electrical instruments from the disturbing effects of external electrostatic or magnetic fields which otherwise would lead to errors of indication. The fundamental principle of all methods of shielding is that of enclosing the movement of the instrument in an envelope into which the extraneous flux is diverted.

The shielding of electrostatic instruments is very simply effected by connecting the fixed charged conductor to the metallic case, which must then be connected to the earthed pole of the supply. If neither pole of the supply is earthed the instrument must be provided with an additional casing, either of insulating material, or of metal, insulated from the live case and connected to earth.

Electro-Magnetic Shielding. The effective shielding of electro-magnetic instruments from the effects of external magnetic fields is not so simple. The usual method is to enclose the movement of the instrument in an envelope of magnetic material, which envelope is relied upon to divert or shunt the magnetic flux from the movement. The effectiveness of this shunting depends upon the permeability of the material of the shield. As the permeability of cast iron or ordinary sheet steels is very low for weak fields, the shunting effect when these materials are used can only be partial. The use of mumetal gives much superior shielding since this material has a maximum permeability with very low flux densities. This matter is further considered under the heading Mumetal.

Shielding can be made much more efficient by the use of two magnetic envelopes, the one within the other. With this type of construction the inner shield diverts from the movement a large fraction of the minute flux which has escaped the outer shield, so that the residue which penetrates to the movement is negligible.

Magnetic shields for instruments should be as deep as possible. Apertures to accommodate the connecting leads and for the pointer are essential, but these should be as small as practicable.

It is very important to avoid any possibility of a permanent polarity being imparted to a magnetic shield if the instrument should be exposed to a strong external field. The use of mumetal (*q.v.*) is the best way of avoiding such a possibility, as the remanence of this alloy is abnormally low, and it is incapable of retaining any appreciable permanent magnetism. High-grade instruments, even though they are efficiently shielded, should, however, always be carefully kept away from any position where there is a risk of exposure to a strong external magnetic field.

SHOCK, ELECTRIC: THE RISKS AND TREATMENT

By L. J. Luffingham

Every worker in the electrical industry is exposed to the risk of shock, whether due to the carelessness born of familiarity or to the failure of insulation or earthing, and under certain circumstances serious danger is not limited to high voltage work Accordingly, the present work would not be complete without the clear instructions given here for rescue and life saving. See Home Office Regulations.

Danger to life from electric shock is not dependent solely on the supply pressure. It is only necessary for a very small current to flow through the body for fatal results to ensue, and that is determined by the total resistance in circuit. Thus, standing on a carpet or wooden floor, which are good insulators, probably only a slightly objectional shock sensation would be experienced on touching a 250-volt conductor. But standing in a bath, which has no insulation value to earth, and grasping a radiator or other appliance that has become live through breakdown of its insulation, would of a certainty prove fatal. There is nothing to check the flow of current in the latter case.

As far as the human body is concerned, its electrical resistance is virtually that of the skin only. If that is lessened or destroyed by perspiration, or by being in contact with water, there is negligible resistance to check current flow. Under the latter conditions very low pressures may prove fatal, *e.g.* 60 volts A.C. Alternating current represents a greater shock risk than D.C. for a given voltage, as the crest voltage of the A.C. wave is considerably higher than the R.M.S. value.

Methods of Rescue. One of the effects of an electric current passing through the body is to contract the muscles. Thus it sometimes happens that a workman having grasped a live conductor accidentally is unable to let go. Anyone attempting to remove him may become similarly involved unless proper precautions are taken. It is advisable to stand on a dry wooden chair, or pull the victim free by using a dry coat, dry rope, or any other means that will insert high resistance between the rescuer and the source of live current.

If, when removed, the victim is unconscious and has apparently ceased to breathe, artificial respiration should be resorted to at once.

It is most important that efforts to restore life should not be abandoned too soon, even though life appears extinct.

Artificial respiration should be continued if necessary for two hours or longer. Even the verdict of a medical man that the individual is dead, especially if given after a brief examination, cannot be relied on as infallible. Cases have occurred in which life has been restored after as long as four hours of artificial respiration.

There should be the minimum of delay in commencing artificial respiration. It is desirable that smouldering clothes should be extinguished, the victim's mouth inspected to see that it is unobstructed, as by false teeth, and that clothing round the neck and body should be loosened. The shortest possible time should be lost in

SHOCK, ELECTRIC. Fig. 1. The first thing is to lay the patient on his back, open his mouth and ascertain if the throat is clear, depressing the tongue, if necessary, to obtain a view.

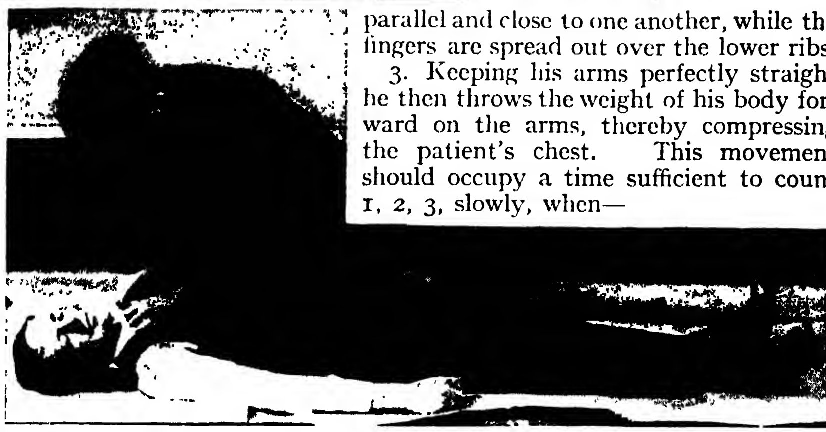


Fig. 2. Having cleared the throat if blocked by any substance, tight clothing about the neck must be loosened. This and the previous step must be taken very quickly, or they can be done by an assistant, as every moment counts.

these preliminaries, and if they can be left to an assistant and artificial respiration started at once, so much the better.

Artificial Respiration. The object of artificial respiration is to restore breathing, as the heart may continue beating after breathing has stopped, and if it is recommenced in time life may return. Of the various methods of artificial respiration that can be used the Schäfer system is by common consent the best. The patient is first laid face downwards, with his arms stretched out beyond his head, and the face turned to one side, so that the mouth and nose may be free. The sequence of operations is as follows:

1. The person who is going to perform artificial respiration, and whom we may call the operator, kneels alongside the patient, or astride him, looking forward, and with his knees about the level of the patient's hips.

2. He places his hands on the patient's back on a level with the lower part of the patient's chest, the thumbs being about parallel and close to one another, while the fingers are spread out over the lower ribs.

3. Keeping his arms perfectly straight he then throws the weight of his body forward on the arms, thereby compressing the patient's chest. This movement should occupy a time sufficient to count 1, 2, 3, slowly, when—

4. The operator should spring back, still keeping his hands on the patient's chest, however. This movement should last long enough to count 1, 2, slowly.

When the weight is taken off the chest it expands and air is drawn into the lungs. These movements are steadily continued till the patient begins to breathe naturally.

In performing artificial respiration two mistakes are often made, and they do much to lessen the usefulness of the operator's exertions if, in fact, they do not make them altogether useless. *One is to place the hands too low down*, so that they are on the patient's loins, rather than on the back of his chest; and *the other is to bend the arms when throwing one's weight on them.*

The speed at which the movements are carried out is also important. The double movement should be gone through about 15 times per minute. The operator can get an idea of the timing by breathing slowly, exhaling as he presses forward and inhaling as he rocks backwards.

SHOCK, ELECTRIC. Fig. 3. The patient is placed on his front, face to one side and arms extended The operator kneels and places his hands on the lower part of the back of the chest. The arms must be kept straight. The exact position is important.

When the patient is breathing naturally he may be turned on his back, or into an easy position on his right side, and something should be done to increase his warmth and improve his circulation. To that end the limbs may be chafed, rubbing always towards the heart. Hot water bottles and blankets, if they can be procured, should be placed about the patient, otherwise such extra clothing as is available. When he can swallow he may be given a little spirits and water, or warm tea or coffee.

If a doctor can be obtained he should give instructions as to when the patient is fit to be moved.

While the patient is being removed, and for an hour or two after he is in bed, a careful watch must be maintained lest his breathing should again cease.

Alternative Method. In certain cases the victim may be badly burned about the chest, from electric arcing, making it impracticable to apply the Schäfer method of resuscitation. Only in such cases should the following, less effective, method be resorted to. Place the patient on his back, with a rolled-up coat or other improvised pillow beneath the shoulders so that the head falls backwards. The tongue should be drawn forward. Kneeling behind the patient with his head between the knees, the operator grasps the patient's arms just below the elbows and draws the arms over his head until horizontal. Pause in this position about two seconds. The patient's arms should then be brought back

Fig. 4. The operator now throws the weight of his body on his arms, kept rigid, and thus compresses the patient's chest driving out air. Still keeping his hands on the chest the operator springs back to the first position, releasing pressure on the chest, which expands, fresh air rushing in.

to either side of the chest, the operator leaning on them to compress the chest inwards. Pause a further two seconds, and repeat the movements at the same rate. To assist the lung inflating effect the patient's arms may be swung outwards when drawing them over his head. Violent movements should be avoided.

SHOP-WINDOW LIGHTING. The primary object of shop-window lighting is to attract attention to the goods which the shopkeeper wishes to display and advertise. This object can only be attained effectively by providing a sufficiently high intensity of illumination, and by ensuring that the attention of the prospective customer is not drawn to the lighting fittings, or distracted by the glare from unshielded lamps, in preference to the actual display.

The intensity recommended for any particular installation depends very largely on that prevailing in the street or district in which the shop is situated. Thus in a side street a lower intensity is permissible than in a main shopping thoroughfare. Suggested values of illumination are as follows, in watts/ft. run: in side streets, 30–50; in moderately lighted main roads, 50–100; in main shopping centres, 100–200.

For further information *see* Floodlighting, where a particular example is calculated in pages 526–27.

The window may be illuminated either from the exterior or interior. In the first case parabolic or elliptical angle reflectors may be employed; these will also illuminate the shop front.

It is not recommended that these should be used without the assistance of some form of interior lighting. Exposed lamps should never be used for this latter service. For inexpensive installations opal or prismatic glass shades may be employed, but if exposed to view these offend against the second canon of good lighting mentioned above, as do the various types of opal diffusive units. The fittings should, as far as possible, be concealed from observers both inside the shop and out.

For general illumination concealed window trough reflectors are very satisfactory and may be so wired that only one lighting point is required per trough (usually of 4 lamps). The troughs may be either of the intensive or extensive type, and may be fitted with coloured screens if so desired. For picking out individual items small floodlighting projectors, with 150–300 W. lamps, are very effective.

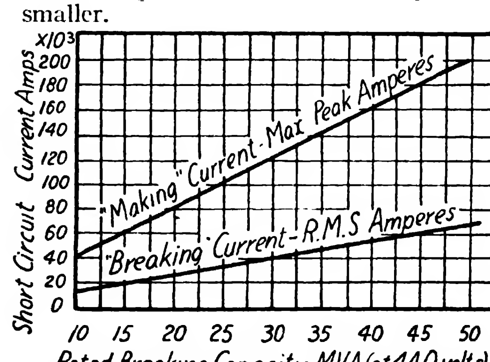
To assist in the general illumination of large displays or to provide the whole of the lighting for small windows a series of strip-lights or tube lamps may be employed. These latter are obtainable in seven standard lengths ranging from 1 ft. to 4 ft. and ratings of 35–55 watts per ft. respectively. *See* Floodlighting; Lamp; Lighting.

SHORT CIRCUIT. An accidental low resistance connexion between two or more conductors of different voltage or between one conductor and earth. Also referred to as S.C. or short or fault.

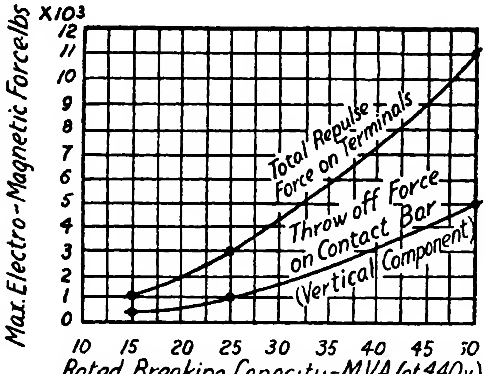
The term is also applied to a connexion made intentionally with the object of bypassing part of a circuit.

Short circuits usually consist of metal to metal contacts between conductors or of incandescent arcs. In either case the resistance of the short circuit is about zero. A very heavy current, therefore, flows through the path provided by the short circuit. This current is referred to as the short circuit current. Its value depends on the resistance and reactance of the generators, transformers and cable through which the current circulates.

D.C. Short Circuit Values. In estimating the values of the short circuit current on D.C. systems the resistance only is taken into account. On A.C. systems the reactance is taken into account and the resistance is neglected because it is very much smaller.



SHORT CIRCUIT. Fig. 1. Making and breaking current values at 440 volts.
Ferguson, Pailin, Ltd



SHORT CIRCUIT. Fig. 2. Electro-magnetic forces on low voltage breakers
Ferguson, Pailin, Ltd.

To calculate the value of current supplied to a short circuit on a D.C. system the combined resistance of the generators on load is added to the combined resistance of the lines connected to the fault, and the voltage of the system is divided by the result.

For instance, on a 500-volt lighting system supplied by two generators, each having 0·2 ohm resistance, if a short circuit occurs at a point supplied by three parallel feeders each of 6 ohms resistance, the total resistance in circuit with the fault will be as follows:

Two generators each 0·2 ohm	=0·1 ohm
Three feeders each 6·0 ohms	=2·0 ohms
Total	=2·1 ohms

and the short circuit current will be:

500 volts divided by 2·1 ohms=238 amps.

A.C. Short Circuit Values. In making a similar calculation for an A.C. system it is not usually convenient to use ohms, because the current is usually fed to the fault through a number of circuits each having a different voltage. For instance, if a fault occurs on the wiring of a house at 230 volts, the current is possibly generated at 11,000 volts, transformed up to 33 kV and transmitted a long distance at this voltage, then transformed down again one or more steps to 400 volts for distribution to the houses. The effect of an ohm in the 33 kV line is less than an ohm in the 400-volt line in the ratio of $\frac{400^2}{33{,}000^2}$.

It is possible to adjust the values of the ohms by this method, but to avoid confusion it is usual to express the reactance as the percentage voltage drop due to the passage of a given number of volt ampères transmitted. For instance, if a transformer has a reactance of 80 per cent. to 100,000 kVA it means that if 100,000 kVA circulates through the transformer the voltage drop is 80 per cent. If a generator of 15,000 kVA capacity has a reactance of 12½ per cent. to its own full load, then eight times full load will give a voltage drop of 100 per cent. The generator will, therefore, supply eight times its own full load to a short circuit across its terminals. A fault of this type is called a dead short.

To calculate the short circuit supplied to a given point on a system the per-

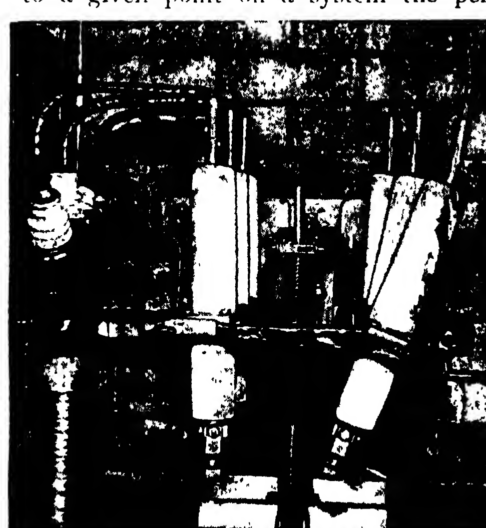


Fig. 3 (left). Effect of arc current on contacts. Fig. 4 (right). Deformation of circuit breaker terminals by the effects of a short circuit current.

SHORT CIRCUIT. Fig. 5. Disastrous effect of oil circuit breaker failure on short circuit.

centage reactances of each part of the system must be expressed as the percentage reactance to the same load. On high power systems the load chosen for this is 100,000 kVA. For instance, if the generator and transformer referred to above are connected in series the total reactance is calculated as follows:

Generator $12\frac{1}{2}$ per cent. reactance to 15,000 kVA
Reactance to 100,000 kVA

$$12\tfrac{1}{2} \times \frac{100}{15} = 83.$$

Transformer reactance to
100,000 kVA = 80 per cent.
Total = 163 per cent.

If a short circuit occurs in the terminals of the transformer the kVA supplied is calculated as follows:

The voltage drop is 100 per cent. because there is a dead short.

The reactance is 163 per cent., therefore 100,000 kVA would give a theoretical voltage drop of 163 per cent.

The kVA for 100 per cent drop is, therefore, $\frac{100{,}000 \times 100}{163} = 61{,}000$ kVA. If the voltage at the transformer terminals is 33 kV. the current is $\frac{61{,}000}{33\sqrt{3}} = 1070$ amps.

When a dead short circuit occurs close to the terminals of a generator the amount of current that circulates is enormous and there is a danger of the windings being torn out of their positions in the machine and of the connexions and bus-bars (*q.v.*) being twisted out of shape. For this reason the windings are all clamped firmly in position and the connexions are spaced widely apart and provided with strong supports.

The circulation of the short circuit current also produces dangerous overheating and grave danger of fire if the current is not quickly cut off.

Avoidance of Short Circuits. In house wiring short circuits occur very frequently in fittings due to carelessness in stripping back insulation. This leads to an unnecessary amount of conductor being bared and the loose ends consequently come in contact. In wiring up a fitting care should also be taken to secure the cable at the point of entry so that no sharp edges can cut into or chafe the insulation. Pendant fittings are usually provided with wooden wedges to grip the cable. If they are left out the metal part of the fitting presses on the insulation and will cut through it in time. Pendant type fittings expose the cables to excessive heat and consequent weakening of the insulation.

The leads to portable apparatus are particularly liable to damage due to constant pulling about and the insulation becomes weak near the point of attachment. If a short circuit occurs at this point the person using the apparatus may suffer from severe burns or electric shock. Leads on such apparatus should, therefore, be renewed at the first sign of wear.

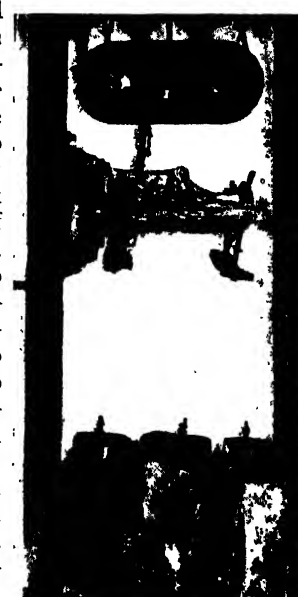


Fig. 6. Example of failure of circuit breaker having inadequate rupturing capacity.

With good modern house wiring short circuits in the wiring itself should never occur (*see* Wiring), but there is always a danger of a faulty switch providing a short circuit to earth. For this reason switch-covers should preferably be made of insulating material, such as bakelite.

On overhead lines short circuits can be avoided by keeping the insulators clean. This does not present any serious difficulty, except in places exposed to salt-laden winds or fogs that deposit carbon on the insulator surfaces.

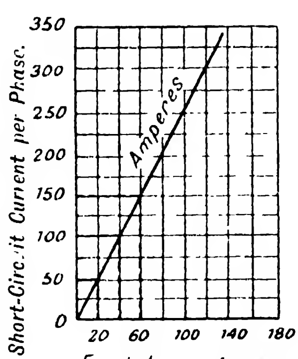
In high-voltage wiring the phases are separated from each other by wide spaces and barriers are provided between conductors at different voltages.

Men working close to bare conductors at high voltage should keep in mind the risk of accidental contact of long metallic appliances, such as steel tapes, and the use of such things should be avoided.

Apart from the risk of electric shock (*q.v.*), a short circuit generates a very high temperature arc, and of all injuries, extensive burns are the most likely to prove fatal. *See* Earths and Earthing, Protective Devices, Short-Circuit Current; Synchronous Machine; Tests; Wiring.

SHORT-CIRCUIT CHARACTERISTIC. Besides load and no-load characteristics (*q.v.*), another useful alternator curve is obtained by running the machine at normal speed, and with the fields unexcited, short-circuiting the terminals through a suitable ammeter.

A small and gradually increasing excitation current is then passed through the field windings until the ammeter indicates the maximum safe current which can be passed through the armature coils. Plotting simultaneous readings of the excitation and armature currents respectively, on squared paper, gives the short-circuit characteristic.



SHORT-CIRCUIT CHARACTERISTIC. Fig. 1. Characteristics of a 3,000 kW. alternator.

This short-circuit excitation affords a measure of the inductive reaction of the armature for the various currents considered. Apart from the ohmic resistance, which in this case is practically negligible, the E.M.F. due to the field excitation is nearly balanced by the back E.M.F. due to the inductance of the armature under the particular current dealt with.

The short-circuit excitation, therefore, gives a practical measure of the reactive ampère-turns of the armature for any particular current. Considered in conjunction with the no-load characteristic (*q.v.*), it enables us to calculate the voltage drop in the alternator under full load; or, what is more important, to calculate the excitation required to maintain a constant P.D. at the terminals when the machine is loaded with any load which it can safely carry.

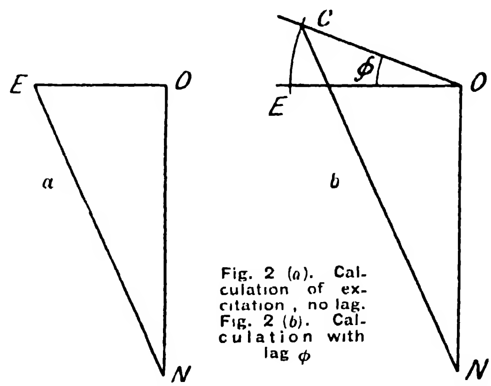


Fig. 2 (*a*). Calculation of excitation, no lag. Fig. 2 (*b*). Calculation with lag ϕ

The excitation required for a given current load is read off from the short-circuit curve. Also, the excitation necessary to give the desired P.D. on the unloaded machine is ascertained from the no-load curve. These two excitations added together will give the main part of the excitation wanted. As the no-load current is in quadrature with its E.M.F. the quantities must, however, be added vectorially, as shown in Fig. 2.

For unity power factor the inductive reactance of the armature is in quadrature with the current which is in step with the P.D. at the terminals. The armature reactance OE (Fig. 2a) is, therefore, at right angles to the no-load excitation ON. The approximate excitation required to give the necessary P.D. at the terminals is, therefore, given by NE.

For a power factor less than unity, the current in the armature lags or leads the E.M.F. by an angle ϕ, and the magnetic reaction on the field flux has to be taken into account. The line OC (Fig. 2b) is drawn at an angle ϕ to OE, and the excitation measured along this line instead of OE because the inductive reactance is still in quadrature with the armature current. The line CN now gives the necessary excitation and further investigations in this direction lead to a predetermination of the regulation (*q.v.*) of a machine and similar analyses.

SHORT-CIRCUIT CURRENT. From the short-circuit characteristic, we can obtain the value of the short-circuit current under normal conditions of speed and excitation. In a machine with good inherent regulation (*q.v.*) the value of the short-circuit current approaches that of the full-load current.

In practice, however, when an alternator is short-circuited, there is an initial rush of current far higher than the final short-circuit current, and both the transient and permanent portions of the short-circuit current must be considered. The latter can easily be calculated, as shown above, but the former takes the form of a powerful surge of a more or less transitory nature. It is this surge of current which is liable to cause considerable damage to windings and insulation, and the involved nature of the calculations concerned in its estimation render it peculiarly difficult to reach a definite and conclusive figure. In complicated systems, models of the lay-out have been constructed and the current values attained found by actual test, and this method seems as good as any other. The effects of short-circuit currents are discussed under Alternator ; Faults ; Short Circuit, *etc.*

SHORT-CIRCUITED ROTOR. *See* Squirrel-Cage Motor.

SHORT-CIRCUITING DEVICE. A means by which a circuit, or apparatus forming a part of a circuit, may be cut out or prevented from performing its usual function in the circuit. There are numerous applications of short-circuiting devices employed in electrical work, but as a rule they depend upon the current choosing the path of lesser resistance. For this reason it is important to ensure that the conductor forming the short-circuiting device has a minimum of resistance, which must in any case be considerably lower than that part of a circuit it is desired to short.

A common application of a short-circuiting device is in connexion with the majority of motor starters where direct current is used. An electro-magnet is situated in the starter, and retains the switch arm by virtue of its magnetic influence over the latter.

Another electro-magnet fitted to the starter has an armature to which are attached contact pieces. When the load of the motor increases beyond a point consistent with its safety, the armature bearing the contact pieces is raised and short-circuits the magnet retaining the switch arm. As the arm is spring loaded, it flies back and the motor is stopped. A somewhat similar device is often used with dynamos used for charging accumulators and other purposes, and it is important to see that the device is functioning correctly, as the contacts tend to become dirty, and if they fail to operate considerable damage may be done to the plant or accumulators.

For starting alternating-current motors a short-circuiting device is often incorporated within the rotor. The slip-rings are short-circuited on attaining speed and the brushes can then be raised, enabling the machine to run as a purely inductive motor. The device, in this case, may be automatic or operated by hand, various methods being available such as a floating collar on the shaft, centrifugal devices, etc. *See further under* Cut-Out ; Induction Motor ; Starter, *etc.*

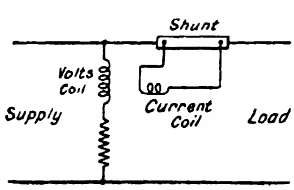
SHORT-TYPE COIL. In the barrel-type winding (*q.v.*), the end connexions are laid on a cylindrical surface. This considerably extends the axial length, and in cases where space is limited the short-type coil method of winding is therefore adopted. This consists in bending the end connexions round against the end of the core to form, as it were, a binding to the core sides. This gives considerable saving in space, but is slightly more complicated than the barrel-type.

SHORT WAVE. *See* Aerial ; Ultra-Short Wave.

SHUNT (Shunt Circuit, Shunt Winding, and Shunt Coil). Terms involving the word "shunt" are numerous and the word has somewhat different shades of meaning. In the following definitions, therefore, as many cases of usage are covered as are reasonable, and important exceptions mentioned, while some special applications of the term are considered later.

When two conducting paths are connected in parallel, the current splits up between them, and part flows through each. The path of higher resistance, through which the smaller part of the current flows, is called the "shunt circuit." This name is usually given when the ratio of the currents in the two paths is large, an exception being made in the case of current-measuring instruments. In that case the part of the circuit in parallel with the instrument coil is called the shunt circuit, irrespective of current values, and when it consists of a single resistance only, this resistance is called a "shunt." When a shunt circuit consists of two or more coils in series and the coils are used for producing a magnetic field, the circuit is spoken of as a "shunt winding," while a single coil is spoken of as a "shunt coil."

The Instrument Shunt. As stated above, this term is used mainly in instrument work. Its function is to divert part of the current from the instrument, but the current flowing through the instrument is a fixed fraction of the total current in the instrument and shunt circuits, so that by indicating this fraction the instrument indicates the total current to scale. In accurate measurements by bridge methods it is sometimes necessary to have a comparatively insensitive instrument for making preliminary adjustments, but a more sensitive one as balance is reached. A sensitive instrument can be made insensitive so that it will indicate larger currents without suffering damage, by placing a variable shunt across it, the shunt being taken out of circuit when required.



SHUNT. A wattmeter or watt-hour meter circuit.

A special type of shunt, known as a "Universal Shunt," is usually used for this. Its special advantage is that it can be used to give certain ranges of sensitivity, fixed by the shunt itself, no matter what may be the resistance of the galvanometer to which it is connected. When a galvanometer is used for measuring small currents it is sometimes more convenient to make the instrument direct reading, or at least to have a scale factor which can easily be used. This can often be achieved by shunting the instrument with a resistance many times its own value. The same method is often used on voltmeters for scale correction where the instrument is adjusted by shunting the coil with a high resistance (*see further under* Shunt Box).

A shunt is used on all moving-coil ammeters and in the current circuit of D.C. wattmeters and watt-hour meters for higher current instruments. Here the shunt carries much the greater part of the current to be measured, only a fraction passing through the instrument coil. In this case, although the instrument strictly forms a shunt circuit to the shunt, this term is never used. "Shunt circuit" in this connexion is used to indicate the part of the circuit in which the shunt is connected, and the instrument branch is distinguished by being called the "potential circuit."

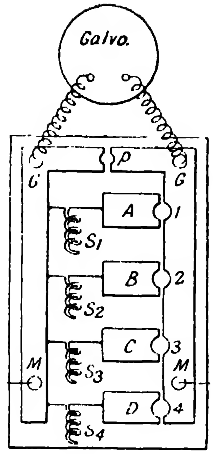
In wattmeters the possibility of confusion is even greater. Referring to the diagram, it is seen that the circuit containing the volts coil is in parallel with the load, and so forms a shunt circuit.

A shunt is in use for measuring the current so that to avoid confusion the terms "pressure circuit" and "current circuit" are used to indicate the two parts of the instrument connected between the pressure and current terminals. This also applies to watt-hour meters, and relays with wattmeter movements.

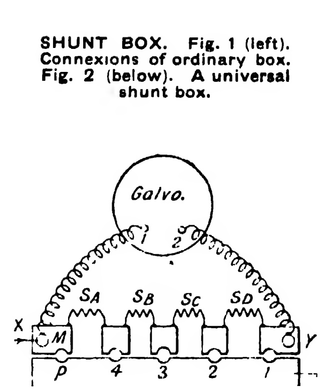
Shunt Coil. In arc-lamps with automatic carbon feeding the carbons have a coil connected in series with them and one connected across the arc, this latter being called a "shunt coil." The series coil tends to open the carbons and the shunt coil to close them, and the mechanism is so adjusted that the forces due to the two coils just balance when the arc

is running at the correct value of current at the correct arc length.

This term is sometimes used in place of "volts coil" to distinguish the coil in the pressure circuit of a wattmeter, etc., from the current or series coil. In the same way the two coils on the pole of a compound generator or motor are distinguished by the names "shunt coil" and "series coil." The former is part of the shunt circuit, while the latter carries all or part of the main current.



SHUNT BOX. Fig. 1 (left). Connexions of ordinary box. Fig. 2 (below). A universal shunt box.



Shunt Winding. The application of this term is limited to denote the part of the shunt circuit formed by the field coils on a shunt- or compound-wound machine. When referring to machines of these types "shunt circuit" is used to denote the circuit consisting of field winding regulating resistance, and no-volt coil. *See* Circuit; Compound Wound; Parallel Connexion; Series Coil; Shunt-Wound Generator.

SHUNT BOX. The circumstances under which it becomes necessary to use a shunt on a galvanometer, and the principles underlying the use of shunts, are explained under Shunt (*q.v.*). The necessity arises more frequently when using sensitive galvanometers than with less sensitive instruments, though the method is applicable to any galvanometer. For the former, however, it is customary to wind special coils and place them in resistance boxes, which should always accompany the galvanometer for which they are wound. The reason for this is that the effect of a shunt of a certain resistance depends on the resistance of the galvanometer with which it is used. For if the resistance of the shunt be $\frac{1}{n}$th of the resistance of the galvanometer, the total current in the main circuit is $n + 1$ times the current measured by the galvanometer. This number $n + 1$ is known as the multiplying power of the shunt.

In constructing such resistance boxes the fact that the resistance of metals varies with the temperature, and that different metals have different temperature coefficients, must be taken into account. This renders it necessary that the wire in the shunt box should be of the same material as the wire with which the galvanometer is wound. Otherwise the ratio $\frac{1}{n}$ of the resistances of the two would change with the temperature, and the multiplying power of the shunt depend on the temperature holding at the moment of measurement.

The condition that each galvanometer has to have its own box of shunts wound specially for it is both expensive and irksome in practice. Also the fact that different lengths of wire are employed in the various shunts means that the temperature variation does affect the multiplying ratio to some extent. To overcome this special resistance alloys with constant temperature coefficients are employed, and the former difficulty has been overcome by means of the universal shunt.

To understand this we must revert to basic principles. If G and S be resistances of galvanometer and shunt respectively, and the latter be $\frac{1}{n}$th of the former,

$$S = \frac{G}{n} \text{ and } n = \frac{G}{S}$$

whence the multiplying power

$$n + 1 = \frac{G + S}{S}.$$

The universal shunt box is so designed that the numerator of this fraction (G+S) is kept constant, in which case the multiplying power varies inversely as S.

Inspection of Fig. 2 will show that in whichever hole the plug be placed the numerator of the multiplying fraction will be $G + S_A + S_B + S_C + S_D$, and the denominator consist of the coils on the left-hand side of the plug. For instance, if the plug be inserted in hole No. 3, the

current divides at X and the galvanometer section passes through the galvanometer to Y and then through coils S_C and S_D; the shunt section passes through coils S_A and S_B, and the two sections unite at the plug No. 3, and pass together to the terminal M. The resistance of the galvanometer section is, therefore, $G + S_C + S_D$ and of the shunt $S_A + S_B$ giving the multiplying power

$$n + 1 = \frac{G + S_A + S_B + S_C + S_D}{S_A + S_B}$$

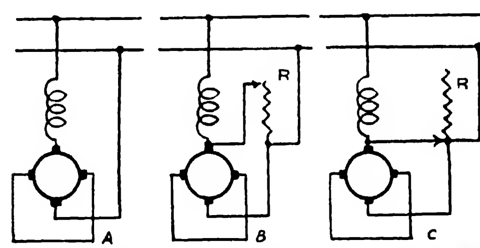
The arrangement is most sensitive when the plug is in hole No. 1, and the relative resistances S_A, S_B, etc., are so arranged as to give convenient integral multiplying powers when the plug is in either of the holes 2, 3, or 4.

When a galvanometer is shunted the resistance of the complete circuit is obviously decreased. This change will affect the value of the main current unless a compensating resistance is introduced into the main circuit. Shunt boxes can be arranged to do this and are then known as constant-current shunt boxes.

SHUNT CHARACTERISTIC. In a similar manner to the series characteristic (*q.v.*) obtained with series-wound machines, curves may be obtained in connexion with shunt-wound machines. It is usual to plot a curve known as the magnetization curve and one called the external characteristic, the first being the no-load curve (*q.v.*), and the latter the load characteristic. The magnetization curve affords a direct measurement of the flux threading the armature and the slope is an indication of the relative reluctances of air-gap and iron, since, if the former is unduly high, the slope will be less steep than it should be, and the curve will not bend into a more horizontal direction until the exciting current has reached an unduly high value.

The external or load characteristic is obtained just as with a series machine, terminal voltage being plotted vertically at a constant speed, against varying current in the external circuit, plotted horizontally. The external characteristic is the antithesis of that of the series machine, and rises to its maximum voltage on open circuit. On the circuit being closed through a high and gradually decreasing resistance, the curve is at first a straight line with a slight downward slope, which, as the resistance continues to decrease, increases until in an old type of machine the curve turns round and comes back to the origin in an almost straight line. With a modern design, however, the current required to obtain readings at the bend of the curve is beyond the limits of the machine, since designers always work on the initial straight part of the curve. *See* Falling Characteristic; No-Load Characteristic.

SHUNT-CONDUCTION MOTOR. A class of A.C. commutator motor having characteristics similar to those of the shunt D.C. motor. It differs from the shunt-induction motor (*q.v.*) in constructional details and in that the stator winding is connected to the armature electrically. The two types of machine are theoretically identical. The distinctive features of all types of A.C. shunt machines are the two sets of brushes, one set being electrically at right angles to the other.



SHUNT-CONDUCTION MOTOR: (*A*) one brushset connected through an inductance for speed regulation; (*B*) starting as a compensated repulsion motor; (*C*) resistance R cut out.

In the conduction motor the main stator winding is connected across the supply and to the brushes which are coaxial with this winding. The other brush set is short-circuited on itself or through a regulating inductance, or capacity, these latter connexions being employed for speed regulation (Fig. 1A).

A.C. shunt motors have no starting torque. To overcome this drawback they may be started as a compensated repulsion motor by connecting as shown in Fig. 1B, and then be connected as a shunt-conduction motor when up to by gradually cutting out resistance R until the starter is in the second position (Fig. 1C).

SHUNT EXCITATION. In a shunt excited machine, the field coils are connected to the main terminals, being in

parallel with the armature winding itself. The falling voltage at the terminals lowers the shunt current in proportion. On short circuit the terminal voltage and the field current are zero, and the maximum no-load voltage depends on the resistance in the field circuit. The armature resistance causes a voltage drop which lowers terminal voltage by I_A R_A, where I_A and R_A are armature current and resistance. *See further under* Falling Characteristic; Shunt Characteristic; Shunt-Wound Generator, *etc.*

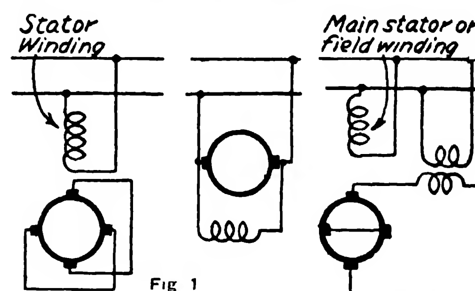
SHUNT-INDUCTION MOTOR. A class of A.C. commutator motor having operating characteristics similar to those of the D.C. shunt motor (*i.e.* approximately constant speed at all loads), but which differs from the D.C. machine considerably in construction. Fig. 1 (*a*) shows the electrical connexions of the bipolar shunt-induction motor, which should be compared with those of the D.C. shunt motor, Fig. 1 (*b*). The shunt-induction motor has a distributed field winding mounted in a slotted stator. This winding is not connected in parallel with the armature, as is the case in the D.C. machine, nor is there any electrical connexion between the field or stator winding; the field acting on the armature inductively.

In common with all A.C. motors, the field system is laminated to prevent excessive eddy current losses. In addition, the machine has a wound armature, a commutator, and two sets of brushes. One pair has the same electrical axis as the stator winding, and the other is set at right angles to the first. Both pairs are short-circuited on themselves. This second pair of brushes forms the chief peculiarity of the shunt type of A.C. commutator machine, and distinguishes it from the repulsion motor (*q.v.*). The reason for this second pair of brushes in the case of a bipolar machine (in multipolar machines there are two sets of short-circuited brushes, each consisting of half as many brush-pairs as there are poles, adjacent brushes being set at 90 electrical degrees apart), and the reason why the D.C. shunt connexion is unsuitable for operating off A.C., are as follows.

If a machine having the connexions shown in Fig. 1 (*b*), even though otherwise corresponding to the general construction of an A.C. motor, is connected across an A.C. supply, the field current and consequently the stator flux will lag behind the terminal voltage by almost 90°, whereas the armature current will be closer to the terminal voltage in phase, and will come more and more into phase with this voltage as the motor speeds up. That is, the armature current of such a machine will be practically in quadrature with the flux, and the torque will be negligible, as this is proportional to product of the armature current, flux, and the cosine of the difference in phase angle between them.

To keep the flux and current in phase the field must be supplied by a voltage which leads the line voltage by 90°; on a single-phase machine, the only way of doing this is the method suggested by L. B. Atkinson: namely, to employ a second pair of brushes arranged on the commutator at right angles to the load brushes which carry the main current. The E.M.F. of rotation induced in this latter pair of brushes by the primary flux will then lead the line E.M.F. by 90°, and produce the type of field required. (Creedy, "Single-Phase Commutator Motors.")

The speed of the shunt-induction motor may be varied by methods which are



SHUNT-INDUCTION MOTOR. Fig. 1 (*a*). Connexions of Atkinson S.I. motor. Fig. 1 (*b*). D.C. shunt motor for comparison. Fig. 2. Creedy S.I motor arranged for variable voltage control.

analogous to those used for the corresponding D.C. machine; by variable voltage control and by adjusting the field excitation. The first may be accomplished by feeding an additional voltage into the armature through the brushes which are coaxial with the stator windings through a transformer or by similar means (Fig. 2). The rotor will speed up until the additional E.M.F. of rotation balances the increased voltage. Increasing the applied stator

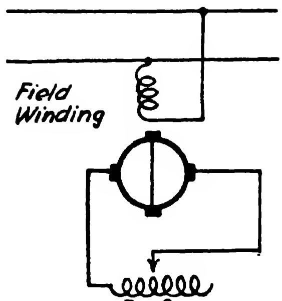


Fig. 3

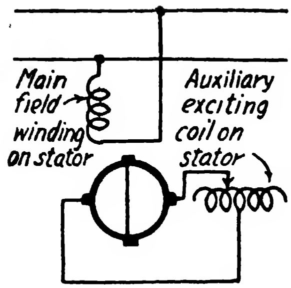


Fig. 4

SHUNT-INDUCTION MOTOR. Fig 3. Arranged for speed control by means of variable inductance. Fig. 4. Speed control by centre-tapped auxiliary coil.

voltage does not, as might at first sight be expected, produce the same result. To vary the field strength, an inductance or capacity is connected across the brushes which give rise to the effective flux, that is, across the brushes which are at right angles to the stator field. The introduction of inductance into this circuit will tend to increase the speed (Fig. 3), whereas increase in capacity will lower the speed.

A third method of speed control, which has no precise analogy in the case of D.C. machines, is to connect a second winding, 90° out of phase with the first, across the secondary brushes. This will either strengthen or weaken the flux according to the relative direction of current flow in this field winding, and whether the M.M.F. of this coil opposes or assists the rotor ampère-turns (Creedy). This effect can be easily obtained by connecting one of the exciting brushes to a centre tap on the auxiliary coil and making the other a movable connexion.

The shunt-induction motor has, like the single-phase induction motor, no starting torque; and the fact that the machine requires a commutator and has a poor power factor and low efficiency explains why it has not found wider application.

By employing a shunt-conduction motor (*q.v.*), which theoretically is identical with the shunt-induction motor, and switching it on to the supply as a repulsion motor, and switching over to shunt conditions as soon as the machine has attained sufficient speed, starting difficulties may be overcome. By employing a centre-tapped speed regulating coil (Fig 4), speed and power factor can also be improved. *See* Commutator Motor; Repulsion Motor; Single-Phase Motor.

SHUNT MOTOR (D.C.). This motor has its field excited by connecting the coils across the mains in parallel with the armature, so that field current depends on mains voltage only. Thus, when the motor is loaded, a larger current will be taken by the armature, and there will be an increased voltage loss in the armature due to its resistance. The back E.M.F. generated will therefore fall, and as the field excitation is independent of the armature, the only way that this can happen is by the speed falling.

The amount by which the speed will fall will depend on the loss in the armature, and as the aim is always to design a machine to be as efficient as possible, and this loss is usually small, the speed of a shunt motor decreases but slightly over the normal range of loads. As the field tends to be weakened by armature reaction this exerts a slight compensating effect which tends to raise the speed.

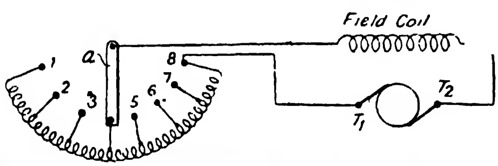
The shunt motor can therefore be used for any drive in which a very nearly constant speed is required. Such applications are to machine tools, some drives in printing presses, spinning frames, looms, and to the driving of generators in motor-generator sets.

Starting and Speed Control. When the motor is at standstill, no back E.M.F. is generated in the armature, so that if it were connected direct to the mains, the current taken, depending only on the armature resistance, which is usually small, would be very large. Except on the very smallest machines, therefore, a resistance must be placed in series with the armature on starting, until the machine has run up to speed, the resistance being gradually cut out as the speed rises. Speed can be controlled by resistance in the armature, but this is very uneconomical and the speed varies greatly with the load. The usual method is to have a variable resistance in the field circuit, and increase the speed by decreasing the field current. The maximum range that can be practically obtained in this way is about a six to one variation. Due to the effects of armature reaction being large relative to the weak field at high speed, the machine becomes unstable and tends to race.

Shunt motors above about 5 h.p. are usually fitted with interpoles, and they are essential to ensure proper commutation where a fairly wide range of speeds is required, even on smaller machines. Reversal of rotation is obtained by reversing either the armature or the field connexions, but changing over the mains will not reverse rotation.

Should a shunt motor start up in the reverse direction and race, it indicates that there is a break in the field circuit, and the rotation is due to the magnetization of the poles produced by armature reaction. *See* Compound Generator; Compound Wound; Direct Current; Series Motor.

SHUNT REGULATOR (Regulating Resistance or Rheostat). An economical, and very often not inconvenient, method of controlling the voltage of a shunt or



SHUNT REGULATOR. Fig. 1. Regulation by resistance in the shunt circuit.

Fig 2

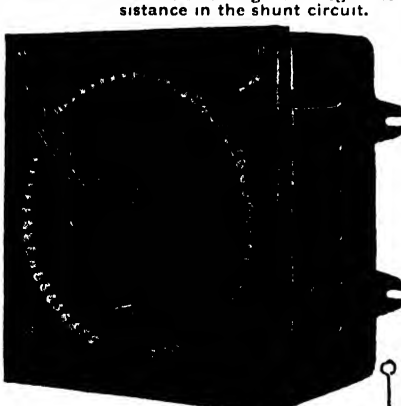


Fig. 3

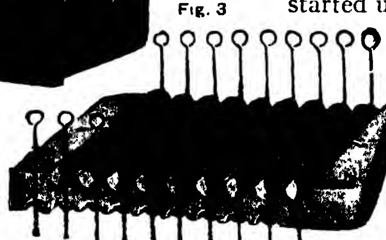


Fig. 2. Front of board type.

Fig. 3. Resistance elements for Fig. 2.
Courtesy Wm. Geipel, Ltd

compound-wound generator, or the speed of a shunt motor, is to introduce a variable resistance into the exciting circuit. The added resistance need only amount to a small percentage of the total output and the energy loss is inconsiderable. For the lower limit of the voltage or for no load, the whole of the resistance is in the circuit, the arrangement being shown diagrammatically in Fig. 1, but with the movable arm *a* on stud 1. As the load increases the tendency of the P.D. at the terminals to fall can be counteracted by moving *a* successively on to studs 2, 3, 4, 5, etc., thus reducing the resistance in the exciting circuit and increasing the excitation as expressed in ampère-turns.

The resistance must be so constructed that it will carry the full exciting current without overheating, and the resistance elements are therefore spirals of nickel-copper or some other low temperature coefficient alloy supported on grooved porcelain formers with anchorages at top and bottom of each groove, as shown in Fig. 3. For details of automatic shunt regulators *see* Starters; Voltage Regulators, *etc.; also* Lift (Electric).

SHUNT WINDING. *See* Shunt-Wound Generator.

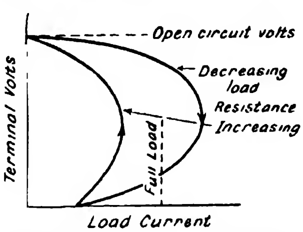
SHUNT-WOUND GENERATOR. When the field excitation in a generator is produced by one winding only, and this is connected in parallel with the load, the generator is said to be shunt wound. The current taken by the field winding of a given machine is determined by the voltage given out by the armature. The field coils are designed so that when the machine is running at its rated speed, the voltage generated in the armature will send a current through the field winding sufficient to produce the ampère-turns necessary to give the flux which will produce this voltage.

It can be seen that when a generator is started up, as it starts rotating no current is flowing in the field winding, so that any voltage generated must be due to the armature conductors cutting the lines of force of the remanent magnetism in the field. The voltage generated in the armature in this way causes a small current to flow in the field winding, and this produces a slightly greater magnetization of the field system. This in turn produces a higher voltage in the armature, causing more current to flow in the field coils, and so the voltage rises. This process is called "building-up," and due to the inductance of the field winding it takes

quite a measurable time, from a few seconds in a small machine to a minute or more in a large one.

When a shunt generator is loaded, some of the E.M.F. generated is used in forcing the current through the armature (armature " lost volts " or " I R drop ") so that the P.D. across the brushes will fall. This drop causes the current in the field to drop, with the result that the E.M.F. generated becomes less. Thus a cumulative action, which is the converse of " building-up," goes on, and the voltage drops as the load increases.

A machine which is driven at constant speed and which has the field resistance kept constant has a characteristic which falls with increasing load, and the drop at full load will usually be but a few per cent. of the open-circuit voltage. If the machine is overloaded, the voltage begins to fall rapidly. (It should be noted that the only method of loading a generator under the conditions stated is by decreasing the value of the resistance of the load.) A stage is then reached at which a further decrease in load resistance produces such a drop in voltage that the net result is to make the current taken fall instead of rise. Eventually the resistance across the machine can be made zero, *i.e.* the machine can be short-circuited and no voltage will appear at the terminals, although a current will flow, due to the E.M.F. of the remanent magnetism.



SHUNT-WOUND GENERATOR. Fig. 1. Characteristics of operation.

If the load resistance is now increased again the current will increase up to a point and then decrease, the voltage finally reaching the original open-circuit value when the load is completely disconnected. This " unloading " curve will not follow the " loading " curve, and the general shape of the " load characteristic," as the curve connecting " load current " and " termina' volts " is called, is shown.

The practical significance of this characteristic of a shunt generator is that the machine cannot be much overloaded and can be short-circuited without damage, provided the short circuit is not applied suddenly. This normally occurs if the insulation of a cable fails, as the fault current is at first of low value, burning the insulation away gradually.

Voltage Regulation. Three methods of varying the voltage generated are possible: (i) by varying the speed of the generator; (ii) by varying the field current by means of a rheostat in series with the field winding; (iii) by means of a third brush (*q.v.*), making use of the effects of armature reaction. The first method is seldom used, as the engine or motor driving the generator is usually designed for economical operation at one speed only, so the second is the one usually found in practice, while the third is mostly used on small battery charging dynamos on automobiles and trains. The voltage control can be manual, or remote controlled by means of push-buttons operating a motor-driven rheostat, while an automatic voltage regulator is sometimes used on larger machines. The range that the field rheostat covers must be such that the lowest voltage required can be obtained when the machine is cold, as the resistance of the field coils increases by about one-third as the machine heats up.

Applications. When only a lighting load is to be supplied a shunt generator is used in preference to a compounded one, as it is important that the voltage applied to lamps should not exceed that for which they are rated. The only machine which can be used satisfactorily for battery charging is a shunt-wound type, as in this case the resistance of the load is low, and the greater part of the generator voltage is used in balancing the battery E.M.F. A very slight change in the generator voltage will produce a large change in charging current, while the voltage variations are so slow and regular that manual control is usually satisfactory. A shunt generator can be used to supply any load which

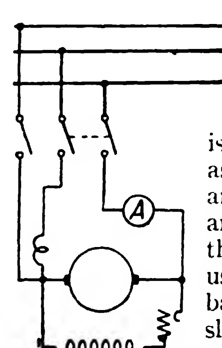


Fig. 2. Compound-wound machine showing shunt winding and equalizing switch and bus-bar (at top).

does not fluctuate rapidly and where there are means of regulating the voltage.

Faults. Failure to Excite. Resistance in the field circuit too high to allow the machine to build up.

After a suddenly applied short circuit the polarity may reverse, or the remanent magnetism be destroyed. The field winding must be connected to some separate source of supply to restore the remanent magnetism, or in the case of reversal, the field connexions can be reversed.

In the case of a small generator, a badly bedded brush may provide sufficient resistance to prevent building up, or if a generator is started up with a load connected, the low external resistance this represents may stop building up.

Unsteady Current and Sparking. These may be caused by badly bedded brushes or wrong brush setting, bad condition of commutator, such as high mica, carbon dust in the space between bars, or loose bars. *See* Charging; Compound-Wound Generator; Generating Sets; Shunt.

SIDE BANDS. A modulated high-frequency carrier wave as used in radio-telephony is in every respect equivalent to the sum of the ***unmodulated*** carrier wave and a number of other unmodulated or constant-amplitude H.F. waves, each with a frequency different from that of the carrier. The frequency difference is in each case that of a corresponding note frequency in the modulated wave and the bands of high frequencies involved on each side of the carrier frequency are known as side bands.

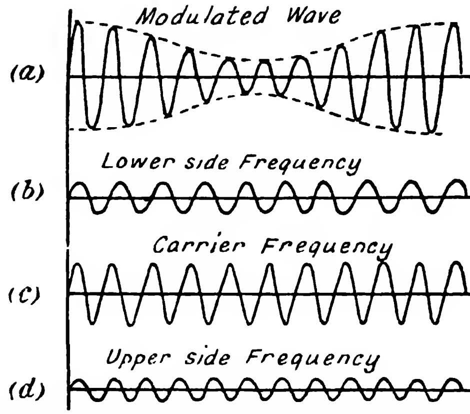
Consider a high-frequency wave modulated so that its amplitude varies about the mean value according to a sine law at an acoustic frequency in the manner shown by curve (*a*) in Fig. 1. Let A denote the amplitude of the unmodulated carrier and B the maximum degree of low-frequency variation from this value. Then the equation to the modulated wave is

$$i = (A + B \cos 2\pi Ft) \sin 2\pi ft,$$

where f is carrier frequency and F is the audio-frequency. By trigonometry this expression is identically the same as

$$i = \tfrac{1}{2}B \sin 2\pi(f - F)t + A \sin 2\pi ft + \tfrac{1}{2}B \sin 2\pi (f + F)t$$

which is the sum of three H.F. waves of



SIDE BANDS. Fig. 1. The modulated wave (*a*) is equivalent to the sum of the H.F. waves (*b*), (*c*) and (*d*).

constant amplitude, the centre one being the carrier wave itself. These waves are shown at (*b*), (*c*) and (*d*) respectively in Fig. 1, where (*c*) is the carrier wave of frequency f. The other two waves, (*b*) and (*d*), have frequencies $f - F$ and $f + F$ respectively on either side of the carrier frequency. They are for this reason called side frequencies.

Thus, a carrier wave modulated at a single low frequency is equivalent to the sum of the unmodulated carrier wave, and a pair of side-frequency waves with frequencies above and below that of the carrier by a number of cycles per second equal to the L.F. modulation. In a normal transmission where the whole range of low frequencies is present, say up to 5,000 c.p.s., there will be a band of side frequencies on each side of the carrier frequency, the total band width occupied being 10 kilocycles. Side bands in relation to tuned circuits are considered under Selectivity. *See* Band-Pass Filter; Modulation; *also* Carrier Wave.

SIGNAL STRENGTH (in Wireless Telephony). There are two separate and distinct ways in which the term "signal strength" is applied in radio work: (A) to denote the intensity of the ether waves in the vicinity of a receiving aerial, and (B) to denote the alternating voltage at the grid of a valve in a receiving set. These are dealt with separately.

Signal Strength of Ether Waves. The intensity of the radiation from a transmitting aerial varies with distance in a somewhat irregular manner, depending on the

location of the transmitter, *e.g.* whether on land or sea, and, in the former case, on the nature of the land, for instance, whether flat or mountainous. Then, again, the variation of signal intensity at any given spot is a function of the frequency or wavelength (*see* Skip Distance).

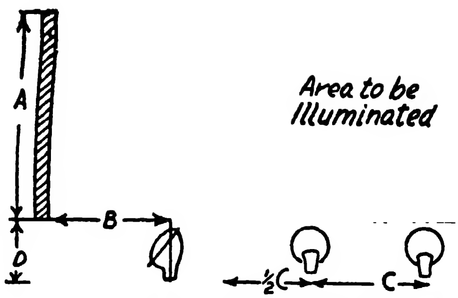
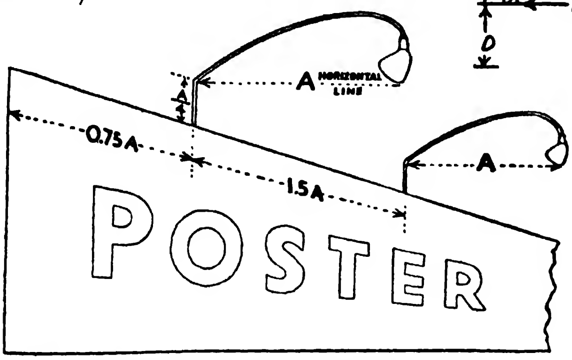


Fig. 2. Relative dimensions for specular floodlights as given in Table 2.
Benjamin Electric, Ltd



SIGN AND POSTER LIGHTING. Fig. 1. Mounting dimensions for elliptical angle reflectors.
Benjamin Electric, Ltd.

The signal strength is expressed usually in millivolts per metre. This is the voltage induced by the ether waves in one metre length of vertical aerial. In testing the suitability of a site for a new transmitting station a temporary or portable transmitter is operated at the spot and measurements are made by means of a calibrated receiver to ascertain the lines of equal signal strength in the surrounding districts and so to enable a topographic map to be drawn.

Signal Strength at Valve Grid. In a valve receiver the high-frequency voltage, due to the unmodulated carrier wave, applied to the grid of a particular valve is referred to as the signal strength at that valve. It is expressed either in R.M.S. value or as voltage amplitude. In the latter case it is sometimes called the signal amplitude. Double the amplitude of voltage at the grid of a valve is sometimes called the "grid swing."

In a receiver it is important that the signal strength at the grid of the detector should be adequate to operate the latter efficiently and for this reason the signal strength at the detector is referred to more frequently than at any other points in the receiver.

L.F. Signal Strength. The term signal strength is also applied to low-frequency circuits. As the low-frequency voltage variations are proportional to the depth of modulation of the carrier wave the L.F. signal strength must necessarily be expressed at either average or maximum percentage modulation.

SIGN AND POSTER LIGHTING. It is now recognized that if posters and vitreous enamelled signs are satisfactorily illuminated their advertising value may be greater during the hours of darkness than in daylight. To secure good results it is necessary to employ suitable reflectors, and to mount them in the positions recommended by the manufacturers. For small (up to 10 ft.) signs "angle" reflectors are recommended. At the present time the elliptical angle reflector is the most popular type, having, for this purpose, largely superseded the earlier parabolic reflector. The mounting dimensions are based on the poster height, those recommended by a manufacturer of elliptical angle reflectors being shown in Fig. 1. More complete details are given in Table 1. If these values are taken, the average

SIGN AND POSTER LIGHTING. TABLE 1

Elliptical Angle										
Lamp Watts	Height of Poster		Distance Out		Spacing: From ends		Spacing: Apart		Height above top	
	ft.	in	ft.	in.	ft.	in.	ft.	in	ft.	in.
60	3	0	3	0	2	3	4	6	0	9
100	4	0	4	0	3	0	6	0	1	0
150	5	0	5	0	3	9	7	6	1	3
200	6	0	6	0	4	6	9	0	1	6
300	7	6	7	6	5	7	11	3	1	9
500	10	0	10	0	7	6	15	0	2	6

TABLE 2. MOUNTING DATA FOR LIGHTING VERTICAL AND HORIZONTAL SURFACES (SPECULAR FLOODS)

Dimensions (see Letters on Diagram)							Illumination (Foot-Candles)						
							General Service Lamps				Floodlight Lamps		
A.	B.		C.		D.		100 w.	150 w	200 w.	300 w.	100 w.	250 w.	500 w
ft.	ft.	in.	ft.	in.	ft.	in.							
6	1	9	2	6	1	0	44	72	100	—	46	—	—
8	2	3	3	0	1	3	27	45	62	100	28	87	—
10	2	9	3	9	1	6	19	32	44	70	21	62	—
12	3	6	4	6	2	0	10	17	23	37	10	32	72
15	4	3	5	6	2	9	7	12	17	28	7	23	52
20	5	9	7	6	3	9	4	6·5	10	15	4·5	13	30
25	7	0	9	3	4	6	2·5	4·5	6·5	10	3	8·5	19
30	8	6	11	3	5	6	—	3	4·5	6·5	2	6	13
35	10	0	13	3	6	6	—	—	3·5	5	—	4·5	9·5

intensity of illumination over the poster will be 10 foot-candles.

For signs exceeding ten feet in height the projection necessary to secure even illumination with the above type of reflector becomes excessive, and it is advisable to employ "specular" floods (Fig. 2). Recommended mounting heights are given in Table 2. *See* Lighting.

SIGNS (Electric). There are, at the present time, so many forms of electric signs on the market, some of them extremely ingenious that it is impossible to describe them all in a short space.

In one of the earliest forms which, in spite of the inroads of "neon" signs, even now, with certain adaptations, gives most satisfactory results, the letters or characters are outlined with incandescent lamps. Although the letters on which the lamps are mounted may be of flatwood or metal battens, hollow metal troughs painted inside with glossy paint, vitreous enamel or chromium plate are to be preferred. The lamps are spaced evenly in one or more rows along the base of the trough, and by a judicious choice of lamps and spacings the light from individual lamps may be blended so that at a distance the lines of light appear to be continuous. Rain or snow should not be allowed to fall on the lamps while they are running, because gasfilled lamps, especially coloured ones, become extremely hot and may crack unless suitably protected.

Such signs may be made to blink by employing them in conjunction with "flashers," and colour changes can be effected in a similar manner. For large signs the current which has to be broken by the flasher when each letter is composed of a number of lamps becomes considerable, and by employing a spun metal letter designed as a reflector it is often possible, even with large letters, to obtain sufficient illumination with one lamp mounted centrally, with consequent reduction in the cost of lamps and size of flasher required. A flasher may also be used in conjunction with a number of open lamps mounted in the form of a large rectangle to spell out letters and words which slowly travel across the face of the sign. Such a sign is known as a "Drifter."

Panoramic Signs. In these, suitable advertising matter is inscribed on a cylinder of translucent material, such as parchment, to which is fitted a series of vanes. The cylinder is mounted concentrically with an incandescent lamp, and is lightly pivoted so that the currents of hot air from the lamp impinge on the vanes, causing the cylinder to rotate. The light may be thrown on to a translucent screen to form a moving image, distorted at its extremities.

Internalite. In this, one edge of a sheet of plate glass polished on one side and etched with a suitable design on the other is fitted into a metal case. The case conceals a striplite which throws light into the body of the glass where it is reflected internally until it reaches the etched pattern, which it illuminates so that it can be read from the front.

Gas Discharge Tubes. The various types of "neon" signs available are discussed under that heading and under Gaseous Discharge Tubes. For external operation they should be mounted on oak, teak, or

metal. Blue (argon-mercury) tubes should be mounted on blue, white or totally reflecting surfaces, never on green or gilt, and for the most vivid red, neon tubes should be mounted on a red background.

The following lamps have recently been introduced by Messrs. Siemens for advertising purposes.

1. "Dobrulux."—Primarily designed for operation on D.C. When used on A.C. a rectifier should be included in the circuit. The lamp is filled with neon and is so constructed that a glow discharge is caused to move continuously round a central core with a gyratory movement. It gives life to a sign, consumes only a watt and has no filament that may be damaged.

SIGNS (ELECTRIC). Fig. 1. Siemens "Dobrulux" neon lamp giving an impression of gyration in the lamp.

2. "Neonic."—This is a neon sign which operates on normal supply voltages without the aid of H.F. coils or H.T. transformers. They are tubular lamps carrying wording within the tube, which when the sign is on the circuit are featured boldly and in the characteristic neon colour.

For many purposes, "tube-lamps" make an effective substitute for neon signs, especially those requiring only small lengths of tubing, and where a high voltage would be particularly objectionable. *See* Gaseous Discharge Lamps; Hot Cathode Lamp; Neon Lamp.

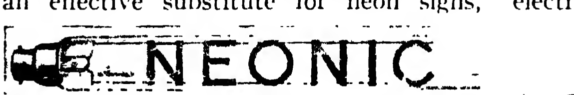


Fig. 2. Tubular "Neonic" lamp carrying wording within the tube.
Siemens Electric Lamps & Supplies, Ltd

SILK-COVERED WIRE. Usually silk is only applied as a covering to pure copper wire of small gauge. It may consist of a double or single covering and, although more expensive than cotton covering, it has several advantages. First, the insulation resistance is higher than cotton, thus allowing the same resistance of insulation to occupy a smaller space. This is important in small and special coil design, because the overall diameter of the coil affects the inductance value. The silk also has a somewhat higher charring temperature than cotton, so that higher current densities may be allowed in similarly disposed windings when this form of insulation is used. Thirdly, its appearance causes it to be used for the outside coils of windings which are open to view, and as it does not deteriorate so easily nor is so absorbent of moisture, is sometimes to be preferred.

SILVER. Metallic chemical element. The symbol of silver is Ag, an abbreviation of the Latin name of the metal, argentum. It is whitish in colour and has a notably high metallic lustre. It is the most malleable and ductile of all metals after gold. The specific gravity varies from 10·47 to 10·62, and the weight per cubic inch is ·38 lb. The melting point of silver is 961° C. (1,762° F.). The latter property permits its use in a hard-soldering process for uniting small metallic parts. Brass, copper, iron, steel, silver and German silver can all be united by this process. The strength of the joint is almost equal to that of a well-brazed joint, and on brasswork can be taken as being practically as strong as the metal itself (*see* Solder).

Silver plays a very important part in electrical matters, being the standard of conductivity both as regards heat and electricity. Its cost prohibits its extensive adoption for conductors, for which copper and aluminium are exclusively employed. Tables of comparison of the relative resistivities of the various metals are given under the heading Conductors (page 281), silver with a specific resistivity of 1·468–1·620 per cm. cube, or 0·578–0·634 per inch cube, being taken as unity.

Silver is also used in computing the ampère, the unit of electrical current, as the constant and steady current which, when passed through a neutral solution of nitrate of silver deposits in one second ·001118 gramme of silver on the cathode, is known as one ampère.

This electrolytic action is employed in the refining of silver from its ores as described under Electrolysis, and also in

the electro-deposition of silver on other metals (*see* Electro-plating). Moving contacts in switchgear are sometimes of silver or are silver coated to minimize sparking and for the sake of improved conductivity.

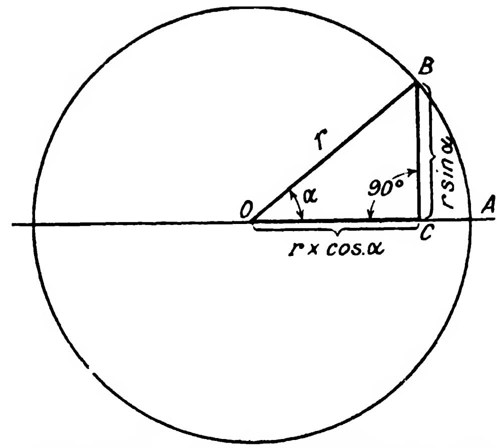
Impurities in silver tend to make it brittle, and only pure silver is used when it is to be drawn into thin wires or otherwise worked mechanically.

SILVER-PLATING. Base metals are covered with a layer of silver, largely for jewellery and culinary purposes. The metal is cleaned, copper-plated and then the silver deposit is put upon the copper. *See* Electro-plating.

SIMPLEX WINDING. The simplest form of any type of armature winding consisting of a single helix wound on the surface of the armature core. Suitable for either lap or wave windings, in the latter case providing two and in the former case p paths through the armature where p is the number of poles.

Simplex windings are commonly employed for outputs exceeding 500 amps., and since the current per armature conductor equals load current divided by p, the number of poles must be sufficient to limit the current to less than 250 amps. per conductor. Equalizing connexions are also required connecting commutator segments which are two pole pitches apart. *See* Multiplex Winding.

SINE CURVE. Draw a line through the centre of any circle such as OA in Fig. 1. Select any point B on the circumference of the circle and draw from it a vertical line on OA cutting it at C. If a line is drawn from O to B the angle α is formed as shown on the figure. The length of BC depends on the angle α and also on the radius of the circle called r in the figure. It is described as the sine of the angle α multiplied by the radius r or briefly written $r \times \sin \alpha$. The length OC is described as the cosine of the angle α multiplied by the radius r. It is written $r \times \cos \alpha$. If B on the figure moves a little way upwards and to the left round the circle, α grows. The line CB also grows. But OC diminishes. When B has moved to the highest possible point on the diagram OB is vertical; α is a right angle; $r \times \sin \alpha$ is equal to r; OC has diminished to zero, so that $r \times \cos \alpha$



SINE CURVE. Fig. 1. Meaning of sine and cosine. Sine of angle α is equal to BC/OB.

is 0. This shows that when α is 90°, sin α is 1 and cos α is 0.

If B moves further round the circle, α becomes an obtuse angle. (*See* Fig. 2.) CB becomes less as B moves to the left and OC grows larger. Hence, while B is as in Fig. 2 an increase in the angle α causes the sine to diminish and the cosine to increase When B reaches the horizontal line, BC disappears to nothing, OC becomes equal to r, and α is 180°.

If the point B moves still further round the circle it reaches the lower half. α is greater than 180°. A vertical line from B on to the horizontal line through the centre of the circle grows as B moves further round until it is equal to r when B is at the lowest point. Here α is 270°. If B moves still further round the circle

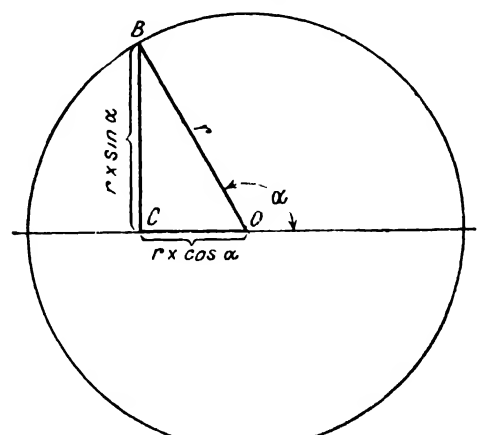
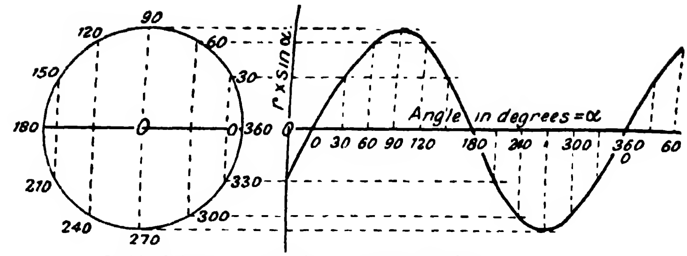


Fig. 2. For an obtuse angle the sine is still given by the ratio of BC/OB.

it eventually reaches the starting point at A on Fig. 1, where α can be called either 360° or 0°. At this point $r \times \sin \alpha$ has again become 0, and $r \times \cos \alpha$ is equal to r.

Plotting a Sine Curve. A sine curve is one for which the successive values of $r \times \sin \alpha$ are plotted against successive values of α, as in Fig. 3. The point B is imagined to have been moved round the circle on the left-hand side of the figure in a counter-clockwise direction. It reaches the points marked 30, 60, 90, etc., in succession. These are values of the angle α in degrees. On the sine curve on the right of the figure these degrees are plotted horizontally as abscissae (*see* Curve), while the vertical distances of the corresponding points from the horizontal line through the centre of the circle are plotted as ordinates. They are successive values of $r \times \sin \alpha$.



SINE CURVE. Fig. 3. Derivation of sine curve is clearly shown in this diagram.

It is usual to speak of the four quadrants of the circle from which the sine curve is derived. The first is from 0° to 90°, the second from 90° to 180°, the third from 180° to 270°, and the fourth from 270° to 360°. For the first and second quadrants the sine curve is considered positive and its curve is above the X axis. For the third and fourth quadrants the sine is negative and its curve below the X axis. The cosine is to the right of the centre of the circle as long as point B is either in the first or fourth quadrants. For these it is said to be positive. When B is in the second and third quadrants the cosine is negative.

The maximum height of a sine curve is called its *amplitude*. It is the value for which $r \times \sin \alpha = r$, so it is equal to the radius of the circle from which the curve can be derived. The distance from one positive maximum to the next is called the *period* of the curve.

The Sine Law. If point B moves round the circle at constant speed the horizontal scale of the sine curve can be marked in time instead of in angular degrees. If B took 360 seconds to make a complete revolution the scale shown in the drawing would represent seconds. If B moved round the whole circle 50 times a second the number 360 on the scale would represent 1/50 second. When any quantity varies with time so that its values can be represented by a sine curve it is said to obey a *sine law*. A swinging pendulum follows such a law. If its distance from the centre position in which it comes to rest is plotted against time we get a sine curve. The same is true of any system which oscillates in a simple way. Movement which follows such a curve is called *simple harmonic motion*. Consequently the properties of sine curves are important for the study of all oscillating or vibratory conditions.

An alternating electric current follows a sine curve very closely. The amplitude of the curve is equal to the peak value of the current and the period in seconds is one divided by the frequency (*q.v.*). In Great Britain the period is 1/50 second.

Any curve which approximates to a sine curve without being a true one is said to be *distorted*. The curve representing an alternating current or voltage nearly always departs slightly from a true sine curve, but it is the aim of the designer of the generating plant to keep distortions to as low a value as possible. The actual shape of the curve is called its *wave form*.

It can be proved that any distortion of a sine curve can be represented as due to other sine curves being superimposed on it which have different amplitudes and periods. Those which produce distortions of importance in electrical engineering always have frequencies which are a multiple of the basic frequency. They are called *harmonics*. The most prominent departure from a true sine curve is due to a triple frequency current called a *third harmonic*. Its period is a third that of the basic curve, or in Great Britain 1/150 second. Other harmonics also occur and

higher ones, such as the eleventh and over, are particularly disturbing to telephone and wireless work because their frequencies are the same as those of audible sound waves. *See* Circle Diagram; Tangent; Trigonometrical Functions; Vector.

SINGLE PHASE. A term used to describe a circuit where there is a single alternating current circulating in one pair of wires as compared with systems in which there are two or more branches or phases. In a two-phase system (*q.v.*) the currents are displaced 90° from each other, in a three-phase system by 120°. *See* Distribution; Phase.

SINGLE-PHASE MOTORS. Generally speaking, motors supplied by single-phase A.C. are not used unless a three-phase supply is for some reason inconvenient to obtain. The reasons for this are:

1. Complications in design of the motors are necessary in order to obtain a starting effort. There is no single-phase motor as simple in design and requiring so little maintenance as the three-phase induction motor (*q.v.*).

2. Alternating current systems are now being standardized for three-phase operation. A single-phase motor takes its supply from two wires only, and therefore loads the three phases unevenly. This is only serious in the case of large motors.

A three-phase supply is not convenient in the following cases and single-phase motors are used:

1. Small domestic motors which take their supply from house wiring which is invariably single phase (*see* Wiring). These include fixed motors such as those used for refrigerators, ventilators, etc., and portable motors such as vacuum cleaners, table fans, hair driers, etc.

2. Portable motor-operated tools used in factories, such as drills, grinders, blowers, etc. A three-phase supply is available for the fixed motors in most factories, but it is more convenient to use single-phase current for portable motors because they take their supply from two wires only. The flexible connexions contain the two supply wires and an earth wire terminated at a three-point plug.

Three-phase supply is also not permissible because the voltage between phases is usually over 400, which is not safe in portable apparatus. The supply is usually taken from one phase to neutral.

3. Railway locomotives which take their supply from a single overhead line with a return path *via* the track. A three-phase supply to a locomotive requires three feed lines and complicated current-collecting devices. Despite this serious disadvantage many railways are equipped for three-phase operation in order to obtain the superior performance of three-phase motors.

4. Motors which have to run equally well on A.C. or D.C. such as small domestic motors, dentists' drills, etc. (*see* Universal Motor). D.C. can be regarded as a single-phase current of zero frequency.

Single-phase motors are usually asynchronous (*q.v.*), but synchronous (*q.v.*) motors are used in special cases. One very common use of the synchronous type is for driving timepieces (*see* Clock, Electric). For larger powers the synchronous type presents special difficulties in design due to the pulsating nature of the magnetic field produced by the stator windings.

Asynchronous motors are divided into two classes:

1. Commutator motors which have armatures with commutators and brush-gear like a D.C. machine.

2. Induction motors similar to three-phase induction motors but having special provision for starting.

There are many types of single-phase motors, which include the following:

Single-Phase Series Motor. This operates on the same principle as the D.C. series motor (*q.v.*). The current circulates through a field winding in series with an armature winding and the driving force arises from the interaction between the magnetic effects of the field and armature windings. If an ordinary D.C. series motor were to be supplied with A.C. of low frequency it would rotate, but satisfactory performance would not be obtained because:

1. The magnetic induction would be so high that the current taken would be very limited in amount, and would be at a very low power factor. The power obtainable would, therefore, be negligible.

2. The alternating magnetic field would produce eddy currents of high value in the solid iron poles and yokes, with serious loss of power and overheating.

3. The field current would produce a

voltage in the coils undergoing commutation (*q.v.*), and there would consequently be heavy sparking at the brushes.

To overcome these difficulties, the following measures are taken :

(1) A fixed compensating winding is provided which produces a magnetic effect in opposition to that of the armature.

(2) The pole pieces and yokes of the magnetic circuits are made of laminated plates like the core of a transformer (*q.v.*).

(3) The current in the compensating windings is shunted by a resistance adjusted so as to produce a phase displacement in such a direction that the resulting magnetic effect in the coil undergoing compensation is opposed to that produced by the field winding.

Motors of this type have been successfully applied to railway traction, the frequency used being about 16 cycles. They are also very largely used for small domestic drives. The universal motor belongs to this class.

Repulsion Motor. This resembles the series motor except that the armature current instead of being supplied in series with the field has current induced in it by transformer action. The brushes are connected together and the armature current circulates round a closed circuit consisting of the commutator windings, the brushes, and the brush connectors.

This affords two important advantages :

1. The armature can operate at a very low voltage whatever the voltage of the supply. This simplifies commutator design.

2. By moving the brushes the angle between the magnetizing forces of armature and field windings is changed and the driving force and transformer action is therefore altered. This provides a convenient method of speed control.

A refinement in design is contained in the Deri Motor (*q.v.*), which is a form of repulsion motor having special brush-gear designed to confine the current in the armature to the part producing the most effective driving force. A further refinement is contained in a machine known as the Winter-Eichbourg-Latour motor (*see* page 1035). In these motors all the windings revolve in such a direction that the voltage due to the rotation cancels out the voltage due to self-induction. This permits operation at a high power factor.

Single-phase Induction Motors. Single-phase induction motors are similar in construction to three-phase induction motors (*see* Induction Motor). If a stationary three-phase induction motor is connected to two wires only of the supply there is no driving force because the field produced by the stator windings pulsates but does not rotate. If a three-phase motor has one of the supply wires disconnected while it is running it will continue to run and will develop a fair amount of power. For single-phase operation, therefore, all that is required is something to provide the starting effort. The following means are used.

Shaded Pole Motor. These motors consist of a stator winding having a number of poles excited by the current taken from the line. Each pole is provided with a second winding which only embraces half of it. This winding is short-circuited. A current is induced in it by transformer action which is slightly out of phase with the current in the main winding and it therefore gives the same effect as a winding connected to a different phase to the main winding. A rotating magnetic field is, therefore, produced similar to that produced in a three-phase induction motor. This field induces a current in the rotor windings and the motor starts up. When the motor gets up to its normal speed the rotor current continues with the stator current to produce a rotating field independently of the shading winding. Motors of this type are in very common use for light, slow speed drives, such as for ceiling fans.

Split Phase Motors. These motors are wound with two sets of windings, one of which receives its supply from the mains direct and the other from the mains through a condenser or inductance. The current is therefore displaced in phase in the two windings and a rotating field is produced. These motors have the same applications as the shaded pole type. *See* Fractional H.P. Motor; Repulsion Motor.

Speed Regulation. Speed regulation of single-phase motors is usually obtained by adjusting the voltage of supply either by tapped transformers or compensators (*see* Starter). In the special types with movable brush-gear described above it is also obtained by moving the brushes.

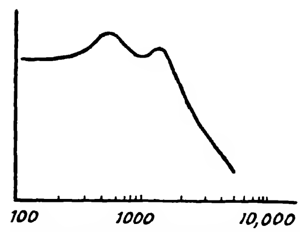
SINGLE-SPAN TUNING. A system of superheterodyne reception in which there is no variable tuning in the signal frequency circuits. The circuit between the aerial and the first valve consists of a filter which passes all frequencies comprising the whole range of wavelengths to be received; for instance, in a broadcast receiver all frequencies corresponding to wavelengths from 200 to 2,000 metres (1,500 to 150 kc.) are passed with more or less equal strength, whereas higher frequencies are cut off.

As in an ordinary superheterodyne receiver, local oscillations are made to interact with the signal frequency oscillations to produce a beat frequency after rectification by the first detector. But this beat frequency is higher than the highest signal frequency received, not lower as in the case of an ordinary superheterodyne.

One of the main advantages of the system is that it requires a single variable " tuning " condenser only, namely that in the oscillator circuit, the necessity for ganged condensers being eliminated altogether. Secondly, no switching is necessary to change from medium to long waves, the whole wavelength range being covered by the single range of oscillator frequencies.

The use of the single tuning condenser is made possible by the high supersonic frequency employed, namely 1,600 kc. per second or more. With this " intermediate " frequency the oscillator would work over the range from 1,750 to 3,100 kc. to cover the complete 200 to 2,000 metre wavelength band, and this requires a maximum to minimum capacity ratio of 3·14 only.

Second channel interference would occur from stations operating over the frequency range of 3,350 to 4,700 kc. if the aerial coupling to the first valve were efficient over that range. For this reason the cut-off should occur at about 1,500 kc. per sec., and filter circuits are designed to this end. The passing of signal frequencies below the useful range is immaterial and the aerial filter circuit can conveniently be in the form of a " low pass " one. But owing to the nature of the aerial circuit itself a symmetrical low pass filter is impossible and a compromise has to be effected. This takes the form of the well-known band-pass filter used for tuning purposes, but the coupling between the units is made sufficiently tight to give a peak separation in the double-hump resonance curve of about 800 kc., one peak occurring at about 400 kc. and the other at about 1,200 kc. The type of response curve obtained with such an arrangement, using capacity coupling, is shown in Fig. 1.



SINGLE-SPAN TUNING. Fig. 1. Response curve of coupled aerial circuits.
Courtesy of " The Wireless World "

A practical circuit arrangement is given in Fig. 2, which shows the essential aerial filter circuit, and the frequency-changer valve of the heptode type. The resistances R_1 and R_2 are included to reduce the peaks of the double-hump band-pass filter characteristic.

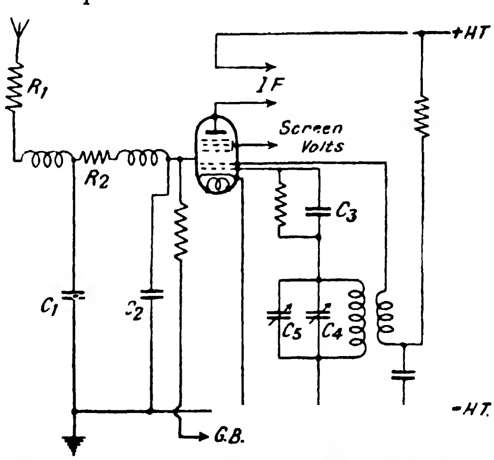


Fig. 2. Simplified diagram showing arrangement of filter and connexions to frequency-changer valve.
Courtesy of " The Wireless World."

The oscillator condenser C_4 is the only one used for tuning, C_5 being a pre-set condenser only. Normal band-pass filters may be used in the 1,600 kc. intermediate frequency circuits and other refinements may be added, according to normal practice. The diagrams are by courtesy of " The Wireless World," to whom the system is due. The single-span tuning principle was not developed and its possibilities remain largely unexploited.

SINOIDAL OR SINUSOIDAL CURRENT, VOLTAGE, WAVE, ETC. A current, voltage or wave that follows a sine law, *i.e.* whose relative instantaneous amplitudes are proportional to the sine of the angle or rotation of the representative vector. Generally, a sinusoidal impulse is free from harmonics and must, therefore, be what is termed a fundamental impulse of pure sine form. *See* Sine Curve. An example of a non-sinusoidal wave form is given under the heading Modulation.

SIX-PHASE CURRENTS. The alternating current side of a rotary converter is usually fed in practice by six-phase currents from the transformers serving them. This results in considerable economies of operation and increases the overall efficiency of the converting plant (*see* Converter). The six currents differ in phase symmetrically by 60°, but the system is limited in practice to this one application.

SIX-WIRE THREE-PHASE SYSTEM. If each of the phases in a three-phase system has its own return wire, and each phase is completely insulated, a six-wire system is obtained enabling each phase to be connected to a separate load.

If, now, the corresponding terminals of the returns of each phase be joined together, three of the wires may be replaced by a single wire of sufficient section to carry the sum of the three currents. The current in the combined line at any instant is $I_1 + I_2 + I_3$, and it can be shown by simple trigonometry that for a balanced load $I_1 + I_2 + I_3 = 0$. The common return wire may then be dispensed with, this method of connexion being known as star connexion (*q.v.*). If, however, the return wire of each phase be connected to the positive lead of the next phase, and so on, delta or mesh connexion (*q.v.*) results.

SKEW WINDING. Also known as basket winding, is a method of winding applied to high-pressure alternators, similar to the former winding of D.C. generators. The end connexions are arranged in two layers, but the coil sides, instead of being in two rings, are all placed at the same distance from the rotor shaft. The coils may be of the same pitch, but are more usually concentric—*i.e.* of different pitches with the smaller coils fitting inside the larger ones, yielding more space for insulation and facilitating the arrangement of the end connexions.

For a monophase machine this arrangement can be made without any crossings, but for a two-phase alternator they cannot be avoided, and one set of connexions is therefore bent up on the "skew," whilst for a three-phase, two sets are skewed to varying degrees. The actual arrangement of the winding is highly involved and beyond the scope of this work.

SKIN EFFECT. Term used in connexion with high-frequency currents, which flow only on the surface of conductors.

In any conductor carrying high-frequency current, eddy currents are induced which tend to neutralize any of the flux cutting the conductor itself. For this reason, the current tends to flow on the outer surface of the wire. In an ordinary direct-current-carrying conductor the whole of the wire is used for carrying the current, so that it is clear that with high-frequency current, for a given wire, the resistance is greater than for direct or low-frequency currents. A metal tube offers to high-frequency currents no more resistance than does a wire of equal surface.

This is one reason why it is best to use stranded cable in high-frequency work, such as radio. Each strand, however, should, for best results, be insulated by a silk or enamel insulating covering, to present the greatest possible surface for a given size of cable. This type of stranded cable offers considerably less resistance than does the ordinary single wire. Litzendraht wire is such a built-up wire. To lessen their high-frequency resistances, transmitter inductances are wound with thin copper strip of large surface, with Litzendraht, or with large copper tubing. Flat copper or phosphor-bronze strip is often used on account of the large surface it presents.

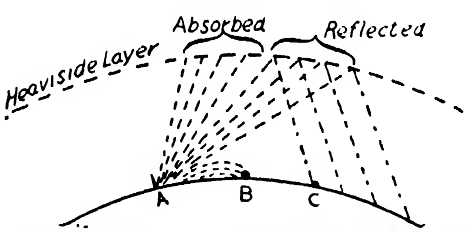
The skin effect is greater in a coil of wire than it is in a straight length of the same wire, owing to the proximity of the turns of wire in the coil to one another.

The resistance of copper conductors to a frequency of one million cycles is approximately three times that of its D.C. resistance. In overhead lines, provision is made for the decreased resistance by substituting cored stranded conductors

for solid drawn wire. In providing for decreased resistance with increased conductor surface area, there is a fortuitous saving in conductor weight which reduces considerably the sag factor. *See* Current Density; High-Frequency Currents; Impedance; Stranded Conductors.

SKIP DISTANCE. A term used in short-wave radio communication to denote the distance beyond the farthest limit of the ground wave at which reception again becomes possible, *i.e.* where the reflected sky wave first reaches the earth.

Waves from the transmitting aerial are radiated at all angles, but the ground wave is soon absorbed by the semiconducting earth, the attenuation increasing with increase of frequency. Those sky waves with an angle to the horizontal not exceeding a certain value are reflected by the ionized layers of the upper atmosphere and reach the earth again at a point C beyond the useful limit B of the ground wave (*see* diagram). In the intermediate space BC no signals are receivable, and this space is called the skip distance.



SKIP DISTANCE. A is transmitter, B the limit of ground wave, C the point of nearest reflected wave. BC equals skip distance.

The skip distance depends on the wavelength and on whether daylight or darkness prevails. For instance, in daylight it is about 160 miles at 40 metres and 500 miles at 20 metres. At night-time the 40-metre skip distance averages 350 miles, whilst the 20-metre wave is not reflected at all. Summer and winter conditions also influence the skip distance. *See* Heaviside Layer.

SLATE. A fine grained rock, originally a fine clay, which cleaves in layers like mica.

Slate is used largely for switchboards. It is, however, very heavy and brittle, and is often displaced by moulded asbestos-mica-bitumen compounds with higher mechanical strength and equal insulating properties. Slabs up to two inches thick have been used for heavy oil switches and similar heavy duty apparatus. Slate is hygroscopic, and for switchboards it must be enamelled and stove-dried.

The specific resistance of slate varies from about 50 to 75 × 10^3 megohms per cm. cube, although samples vary widely, because in the poorer qualities, especially the outcroppings, iron and other minerals are often incorporated. Its dielectric strength is about 30 volts per mil, compared with a maximum of 1,500 volts per mil for mica. *See* Switchboard.

S.L. CABLE. An abbreviation of separate lead-covered cable, and a trade name used for a type of extra high tension 3-core cable, in which each conductor, after insulation, is provided with a lead sheath. The three lead-sheathed cores are then made up into a cable in the usual way. The S.L. cable was designed to overcome the troubles which have been experienced with three-core cables of the older type, due to non-uniformity in the electric stress and to the possibility of the formation of air spaces in the insulation whereby destructive ionization is set up. In the S.L. cable the electric stress is uniform and its direction is radial at all points, while the compactness of the insulation avoids any possibility of ionization.

The losses in S.L. cables are a little greater than in those of the older type, due to the presence of parasitic currents in the sheaths. On the other hand, the three sheaths greatly improve the heat-dissipating properties of the cable, so that the rating of a given section is even greater than that of a similar section of the older type. *See* Cable (page 174), Transmission.

SLIDE RULE. A device for rapid arithmetical work. In its commonest form it consists of a specially constructed wooden ruler about 11 in. long by 1½ in. across. The centre of this is grooved to take a narrower ruler which slides in the groove. The surface of the sliding portion is flush with the fixed part. Scales are marked along the lines adjoining their edges, the same divisions occurring on the fixed and sliding portions. The scales are not evenly divided like those on a foot rule, and do not begin with 0. The division is logarithmic, the first reading being marked 1. The scale goes up to 10, but it is usual to omit the 0 in the last figure.

When the slide rule is used for multiplying two figures, 2 and 3 for instance, it is operated as follows. The sliding portion is moved until the beginning of its scale, marked 1, is opposite 2 on the fixed portion; 3 on the sliding portion is then opposite the answer, namely 6, on the fixed portion. The way to operate a slide rule for division follows from its use in multiplication. Slide rules are fitted with a further sliding portion known as a cursor. This is a small carriage holding a glass plate against the surface of the rule. The glass is marked with a hair line and can be placed in any position to retain an intermediate figure when many successive multiplications and divisions are required for a final result.

The principle of operation of a slide rule is based on the theory of logarithms (*q.v.*). If the divisions were marked evenly and not logarithmically it would add instead of multiplying. When we moved the sliding part until the beginning of its scale was at 2 on the fixed portion we should travel a distance measuring 2 units. If we then moved along the sliding portion another 3 equal divisions we should measure in all 5 units and this is what we should read off on the fixed scale, as anyone can prove by placing two foot rules side by side. Such a slide rule would tell us what 2 + 3 is. But the markings on the slide rule are such that the figures read are not a direct measure of the distance from the beginning of the scale. They are such that while we *read* a certain figure we *measure* its logarithm. The 2 means that the distance of that point from the beginning of the scale represents log 2, while the distance at the point 3 represents log 3. The slide rule operation, therefore, consists in measuring log 2 + log 3. Adding logarithms is the same as multiplying their numbers. So a distance corresponding to log 2 + log 3 is equal to a distance corresponding to log 6. The property of logarithms is such that any figure on a slide rule can stand for the figure as read or that figure multiplied or divided by 10 any number of times.

Most slide rules have a scale along the upper edge of the slide as well as along the lower one. The former is twice as close as the latter. While giving less accuracy the extended set of figures is often convenient. This scale also enables squares and square roots to be obtained easily, because every figure on the lower scale faces its square on the upper one. Further scales are frequently provided on the outer edges of the fixed portion and are used with the help of the cursor. They give such quantities as cubes, cube roots, logarithms and trigonometrical functions. Inch and centimetre scales are also often added to render the slide rule useful as a measuring instrument. *See* Logarithms; Mathematics for Engineers.

SLIP. The speed of an induction motor depends on the number of poles and the frequency of the alternating current supplied, exactly as the frequency of current supplied by an alternator (*q.v.*) is a function of the speed and the number of poles.

In practice, however, the actual speed will be slightly less than the synchronous speed, as at synchronous speed no torque whatever would be exerted. Friction renders this an impossible state, and as the motor is called upon to take up load, the speed falls more and more away from the synchronous speed, until finally, if the load is increased too much, the motor stops; it would, however, run up to speed again if the load were eased. Technically the motor is said to " slip " as the load comes on, and the slip of a motor is the amount of slowing down relatively to the synchronous speed.

The slip may be written as

where n_s and n_r are the speeds of the revolving field in the stator, and that of the rotor, respectively. The slip depends upon the load and in modern machines varies from about 2 per cent. on no-load to 6 per cent. on full-load, so that an induction motor is to all intents and purposes a constant speed machine. After the motor has been loaded up to a certain critical point the torque diminishes suddenly and the motor slows down; considerable speed variation can only be obtained by designing the motor to give a large slip at the sacrifice of considerable loss in efficiency and general performance. *See* Induction Motor.

SLIP CONDUIT. *See* Conduit and Conduit Fittings; Wiring.

SLIP REGULATOR. The induction motor under load slips below the synchronous speed by an amount depending upon the resistance of the rotor winding. The slip is practically proportional to the voltage drop in the rotor, and therefore, by making the rotor of high resistance, or by introducing this resistance externally, the voltage drop can be made very great, and thus the slip may be controlled at will.

The method is very wasteful as a means of controlling the speed of an induction motor, since a reduction of the motor speed to half of the normal, for instance, necessitates a loss of 50 per cent. of the input in the rotor resistance, thus being not only very wasteful of energy, but entailing large and expensive controlling resistances. The Ward Leonard system (*q.v.*) has overcome these disadvantages and automatic slip regulators are incorporated in these and similar flywheel methods of control. *See* Induction Motor; Slip, *etc.*

SLIP-RING. Name given to sliding contacts from which the collecting brushes pick up the current generated by an alternator. They are equivalent to the commutator on a direct current generator.

The rotor of a generator is necessarily kept revolving to generate an electromotive force; it is clear that some sliding contact is necessary to connect the windings to any required outside circuit. The common type of alternator has a stationary armature and its rotating magnets are supplied with D.C. through slip-rings. They are also used to feed A.C. into the rotating part of rotary converters, etc.

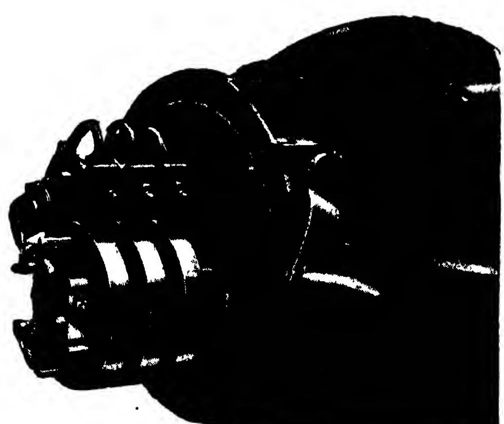
One slip-ring is connected to one end of the armature winding and the other end of the winding is connected to the other slip-ring. The two brushes making contact with the slip-rings are connected up to the outside circuit.

On most standard motors the phosphor bronze slip-rings are mounted inside the end shields, exceptions being in the case of flame-proof and totally enclosed fan-cooled motors. These end shields prevent accidental short-circuiting and can easily be removed for inspection and adjustment of the brush-gear. The photograph shows a close-up view of the slip-rings with end shield removed and the brush lifting and short-circuiting gear can easily be seen.

The slip-rings are shrunk upon mica-insulated steel sleeves. *See* Alternator; Commutator.

SLIP-RING MOTOR. An A.C. motor of the induction type having a wound rotor, the winding of which is brought out to slip-rings for the purpose of starting and speed regulation. The stator of a slip-ring induction motor is of the usual pattern (*see* Induction Motor). The rotor consists of a number of stampings mounted on a shaft, and forms the armature (*q.v.*) of the motor. The outer periphery is slotted with open or semi-closed slots which receive the rotor winding. This is always wound three phase, even when the stator is two phase, since it is not necessary for the number of phases to be the same on both stator and rotor. The stator winding sets up a rotating field, and the rotor rotates in it without regard to the number of phases in the magnetizing winding which produced it. Since a three-phase rotor winding only needs three slip-rings, as against four for a two-phase winding, the advantage is obvious.

These slip-rings are brass or cast-iron rings, insulated from each other and from the frame of the machine. On the inside of each slip-ring is a lug to which is bolted the copper lead coming from the end of the rotor winding, which is star-connected. Pressing on each slip-ring are one or more carbon brushes, from which another lead is taken to one of the rotor terminals. There are three of these, and three conductors are now required to make



SLIP-RING. Brush-lifting and short-circuiting gear are shown; brushes in raised position.
General Electric Co., Ltd., of England.

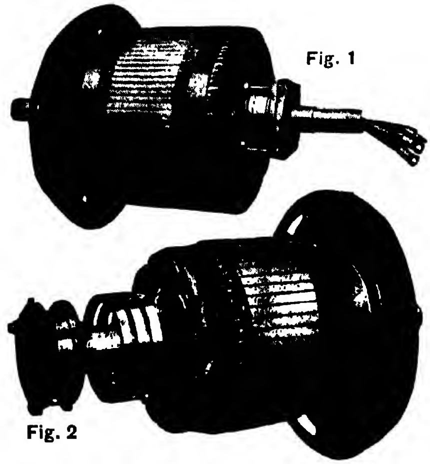


Fig. 1

Fig. 2

SLIP-RING MOTOR. Fig. 1. The rotor winding connexions are made at one end of the rotor to facilitate access for inspection. Fig. 2. Slip-rings, insulated windings and fan are clearly shown.
Lancashire Dynamo & Crypto Co., Ltd

connexion to the three-phase starting resistance. This starter (*q.v.*) possesses three rows of contacts connected to three sets of resistance coils, and moving over these contacts are three arms rigidly fixed to one another, these arms forming a short-circuiting device for the resistance coils.

When the machine is first switched into circuit all the starting resistance is included in the circuit; then the resistance is cut out step by step, until finally the whole of the resistance coils are short circuited. There are now in circuit only the leads from the motor brushes to the starter, perhaps several feet away. This resistance is very low, but it may yet be comparable with the resistance of the rotor winding itself, which is also very low.

Again, there is also included in the circuit the resistance of the contacts on the starter and the resistance of the brush contacts on the slip-rings of the motor. These are certainly comparable in magnitude with the rotor winding resistance and consequently arrangements are made for the motor slip-rings to be directly short-circuited, quite apart from the short circuit brought about by the starter. The usual device is for a metal collar to be forced under the slip-rings, in a direction parallel to the shaft, so as to make direct contact between all three. This operation is performed by means of a lever situated near the end of the shaft, the movement of this lever causing the collar to slide along the shaft. Even the brush-contact resistance of the brushes on the slip-rings is thus eliminated, and when this short-circuiting device is driven home, the brushes on the slip-rings are no longer necessary. They can, therefore, be raised from the slip-rings to reduce wear on them and to do away with their friction loss. This brush-lifting device is operated by the same lever that brought about the short-circuiting of the slip-rings, both being performed by one hand operation. This is highly desirable, as, apart from simplicity of action, it is essential that the two operations should be performed in the proper sequence. The brushes must obviously be raised after, and not before, the slip-rings are short-circuited, and conversely, when the reverse operation is being carried out, the brushes must be lowered into position on the slip-rings before, and not after, the short circuit is removed.

Slip-ring type induction motors are used where a good starting torque is required without an injuriously excessive current passing. By suitably designing the value of the starting resistance, the motor may be made to give maximum torque at zero speed—*i.e.* the moment when it is first switched into circuit. Also, by cutting out this resistance, step by step, the torque can be maintained at a high value throughout the whole of the starting period, so that a slip-ring type induction motor can be employed in a case where it has to start up under a heavy load.

The added resistance in the rotor circuit can also be used for the purposes of speed regulation. When actually running, the insertion of resistance in the rotor circuit causes a reduction in speed, so that any speed can be obtained from zero up to full speed by this means. The method suffers, however, in the matter of efficiency, since reduction of speed in this way, whilst reducing the output of the motor, does not reduce the input. What actually happens is that the energy which is no longer usefully employed in overcoming the load on the motor is now utilized in heating up the rotor resistances, and is therefore wasted.

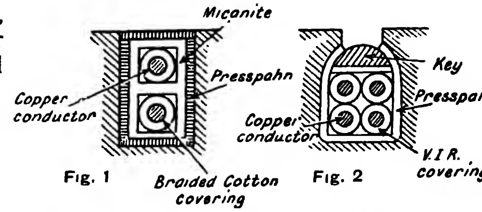
The special faults which may develop, apart from those on any other motor (*see* Faults, Motors), are those associated with the brush-gear on the slip-rings. Each additional feature in the design of a machine is an additional possible source of breakdown, and therefore it is necessary that the slip-rings and brushes be inspected periodically to see that they are in proper working order, and to see that the brushes are renewed when occasion demands. The brushes should not be allowed to remain in position when running, if brush-lifting gear is provided, as otherwise there would be undue wear on the brushes. *See* Induction Motor; Squirrel-Cage Motor.

SLOPE (of Thermionic Valve Characteristic). The steepness of a valve characteristic curve showing the relationship between two of the variable quantities. In the case of the static characteristic curve of grid volts plotted against anode current, the slope expressed in milliampères per volt gives the mutual A.C. conductance (*q.v.*) of the valve.

The slope of the anode voltage/anode current characteristic curve expressed as the ratio of change of volts to change of current gives the anode A.C. resistance (*q.v.*) of the valve. It is sometimes called the "slope resistance." *See* Characteristic.

SLOT. In all slotted core armatures (*q.v.*) the multiple-turn coils lie, as a necessary consequence of the method of winding adopted, two deep in the slot, the right-hand side of one coil coming from one pole lying above or below the left-hand side of another coil coming from the next pole and so on. Between the conductors lying in the top and bottom coils of the slot a considerable difference in potential always exists, owing to the fact that these conductors are brought together from points on the surface of the armature lying under different poles, and good insulation must, therefore, be provided between the top and bottom coils. The core must also be insulated from the conductors, and a sectional diagram illustrating the slot insulation and disposition of conductors in the slot is given. The ratio of the copper in the slot to the total area of the latter is known as the space factor (*q.v.*).

In order that the proportion of copper



SLOT. Fig. 1. Slot insulation for 500-volt. machine. Fig. 2. High-speed armature slot.

to insulation may be as great as possible, it is necessary to keep the number of slots as few as possible; since, obviously, if we use many narrow slots, we cannot get in as much total copper, owing to the necessary thickness of insulation lining the walls of a slot being the same in each slot, independent of the number of slots used.

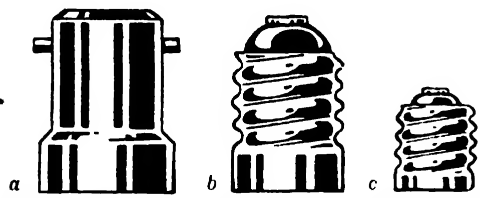
There is an objection, however, to grouping more than three elements of the winding in each slot, since commutation cannot occur simultaneously on all the coils, and group sparking is therefore apt to reveal itself at symmetrical intervals on the commutator. *See* Armature; Former-Wound Coil; Winding, *etc.*

SLOTTED CORE ARMATURE. There are three ways in which the armature conductors may be constituted relative to the iron of the core. They may be entirely buried in the iron, lying in holes within its mass; or the wires may be entirely outside the iron as in smooth-core machines; or they may be wound in slots in the armature core. The latter is the form of construction usually adopted in modern armatures, the coil windings being shaped on formers and then inserted into the slots, the lower conductor in one slot being the upper conductor in a slot one pole pitch away, and so on. The slots are carefully insulated with layers of mica and presspahn, and the conductors held in by the overhang of the teeth at the top of the slot, wooden wedges being driven in to tighten up. In addition, fine wires, well insulated from the conductors, are bound tightly round the finished armature in bands.

The advantages of the slotted core armature over other types include protection against mechanical injury, reduction in length of air gap, adequate ventilation, facilitated winding and accessibility for repairs to conductors. In

high-speed machines special bottle-shaped slots retain the coils in place against the high centrifugal forces set up. *See* Armature; Slot; Winding, *etc.*

SMALL BAYONET CAP (S.B.C.). In both the bayonet and Edison screw types of caps (*q.v.*) a smaller external diameter for the size of the caps has been standardized for use when smaller sizes of bulbs are required for special purposes. For such lamps the B.C. type caps known as S.B.C. are ⅝ inch in diameter, widening



SMALL BAYONET CAP. Full-size comparison of small bayonet, small Edison screw and miniature Edison screw caps.

General Electric Co., Ltd., of England

to ¾ inch diameter at the neck. Full-size comparisons of the small bayonet, the small Edison screw and the miniature Edison screw caps are given in the diagram.

Such caps are extensively used for such small special lamps as are required by miners, by surgeons, for telephone switchboards, for automobile head lights, electric torches, etc., some of which are illustrated under the heading Lamps. *See* Bayonet Cap.

SMALL EDISON SCREW (S.E.S.) CAP. *See* Small Bayonet Cap.

SMEE CELL. A primary cell having electrodes of zinc and platinized silver, with sulphuric acid for electrolyte. The cell now finds no applications.

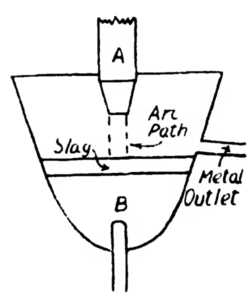
SMOOTH CORE ARMATURE. In the old smooth core type of armature, now obsolete, the armature conductors were wound entirely on the surface and outside the iron of the core. To maintain these conductors in position against the centrifugal and magnetic drag of the rotating armature, driving wedges of hard wood were inserted at intervals round the periphery, the inner ends of the wedges usually passing down between the core discs into appropriate spaces. Another method consisted in placing at intervals strips of hard fibre of the full length of the armature, the inner edges of the strips being recessed in keyways cut in the surface of the armature core. This method wasted some of the space in the active transforming zone of the machines, to avoid which some manufacturers replaced the non-conducting driving strip by a specially deep conductor which, projecting down into the iron bed, helped to give the required mechanical drive.

In all these cases binding wires were essential to counteract the effects of tangential drag. These were insulated from the copper and iron by a layer of insulating tape, and then by pieces of mica.

The smooth core armature was very expensive to wind, was mechanically inferior to the present slotted type, and had other disadvantages. It needed a vast increase in the weight of copper in the field exciting coils, on account of the great length of the air gaps between polar faces and armature core. *See* Slotted Core Armature

SMOOTHING CIRCUIT. A circuit that removes or suppresses ripples or unwanted electrical impulses from transmission from one part of a system to another. For such circuits *see* Battery Eliminator *and* Filter; *also* Rectifier.

SNYDER FURNACE. An arc-operated electric furnace designed to work from single-phase alternating current. The electrodes are vertically erected, the lower one being of steel, water cooled, and embedded in the hearth. The capacity of this furnace is about three tons, and none larger seems to have been constructed on this design. The furnace operation is shown in the diagram. There is nothing complicated in the construction of this furnace. The mechanical and heat requirements are matters of design only, and do not affect the principle of operation.

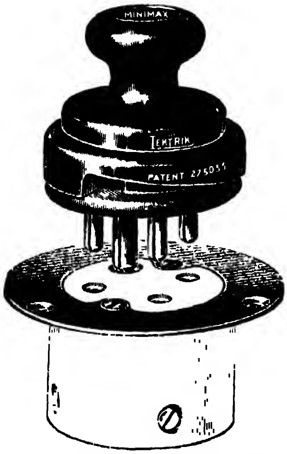


SNYDER FURNACE. Diagrammatic section. A and B are electrodes, B being embedded in the hearth.

SOCKET. Sockets are complementary to plugs. The variety of sockets naturally follows that of plugs, under which heading a selection of different forms is

given, and here others, which are essentially complementary, are also shown. The two sets of illustrations should, therefore, be studied together.

As with plugs the standard is governed by B.S. Specifications No. 372 of 1930 and No. 546 of 1934, whilst they should be installed in accordance with I.E.E. Regs. 607-8 and 1329. The following extracts are reproduced by permission of the B.S.I.



SOCKET. Fig. 1. Four-pin socket with "Minimax" bakelite hand-shield plug adjustable for all sizes of flexible.
J. P. Lundberg & Sons, Ltd

The means for producing the spring pressure (as between plug and socket) shall be an integral part of the socket portion.

Recess for Contact-tubes

The contact-tubes shall be recessed in the insulating-base of the socket portion, or the cover shall be formed so that it is impossible to touch the contact-tubes unintentionally. The holes for the pins through the insulating material for the 15-ampère socket at the point of entry shall not exceed 0·350 inch (8·6 mm.) in diameter, and for the 30-ampère socket at the point of entry shall not exceed 0·375 inch (9·5 mm.) in diameter.

Rating	Withdrawal Pull	
	Min	Max
Ampères	lb	lb
2	3	10
5	5	14
15	7	18
30	9	22

Withdrawal Pull

The force necessary to withdraw a test-plug as specified from a socket-outlet shall be between the limits given in the Table [printed on the right above].

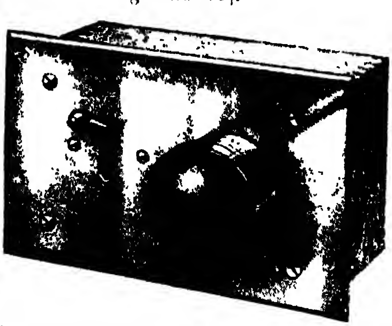
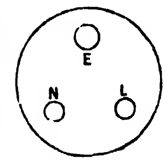


Fig. 2. Interlocked switch socket with standard round pin plug (3-pin) (B.S.S. 546).
M. K. Electric, Ltd

Marking.

All socket-outlets shall be indelibly and distinctly marked to indicate that they are rated at 2 ampères, 5 ampères, 15 ampères or 30 ampères respectively.

Socket-outlets shall also be marked to distinguish the contacts as indicated, which represents a socket-outlet viewed from the front. E represents the earthing contact-tube, L the contact-tube for the live conductor, and N the contact-tube for the neutral conductor.



Socket contacts—Earthing, Neutral, Live.

Plugs shall be marked with the letters E, L and N to indicate the pins corresponding to the contact-tubes in the socket-outlet.

See Connector; Plug.

SOLDER. An alloy used in making a permanent joint between two metals or other alloys. Solders are composed for the main part of two metals, but small amounts of other metals or substances may be added to give special characteristics. The solder used for any particular case must have a lower fusing point than that of either of the two metals it is required to join, but if the best results and most tenacious joints are to be obtained, the solder used must be appropriate to the metals to be joined. Solders are divided into two main classes, soft and hard, the former fusing at a comparatively low temperature and the latter requiring a red heat before fusing.

Soft Solders. These are composed chiefly of lead and tin. The proportion of lead to tin determines the fusing point, which gets lower as the percentage of tin is increased until at 66 per cent. tin and 34 per cent. lead it is 356° F., after which further increases in the percentage of tin result in a higher fusing point. The proportion of tin in the solder determines its classification as common, medium, or fine. Common solder employed for most soft soldering work contains two parts of lead to one part tin.

Hard Solders are used where a hard, tenacious joint is required. The process of hard soldering is also known as brazing, the solder then being called a spelter. The two terms are actually interchangeable, but, commonly, brazing refers to the forming of a joint by a film of brass and

hard soldering with the use of silver solder. The latter is an alloy of silver, copper and zinc or brass, the actual percentages varying with the nature of the work. For hard soldering a red heat is required, thus rendering necessary a blow-pipe flame. The advantages of the hard soldered joint lie in its tenacity and its ability to withstand more heat than the soft soldered joint.

Fluxes. The success of a soldered joint depends amongst other things upon the use of a suitable flux. This is necessary to prevent the oxidation of the heated metals and to dissolve any oxide that may form. The flux required will vary somewhat with the type of solder or spelter used and upon the nature of the metals to be joined. For general purposes, however, for soft soldering use "Fluxite," resin, or killed spirit, and for silver soldering burnt borax or powdered boracic acid. *See* Alloys.

SOLDERING AND SOLDERED JOINT. Soldering is a method of consolidating a joint. It is the most commonly used method of effecting an electrical and mechanical junction between copper conductors by means of the adhesive metallic alloy known as solder (*q.v.*) which consists of tin and lead. In the case of electrical work soft solder is used and is usually made up of a half-and-half alloy of the two metals, having a fusing temperature of 370° F.

Soldering is carried out by two distinct methods. One makes use of a soldering iron which is an instrument carrying at its head a block of copper bevelled towards a point; this must be cleaned thoroughly (preferably with a file), treated with flux and "tinned" by melting a little solder over its face (when hot and clean) which adheres to the copper, giving it a tinned appearance.

The other method is "wiping" in which solder is applied by being melted from the end of a rod of solder on to the joint to be wiped—usually lead sheathing—by means of a blow lamp, and is wiped on to the object to be soldered in a plastic state with a piece of moleskin, leather or cloth.

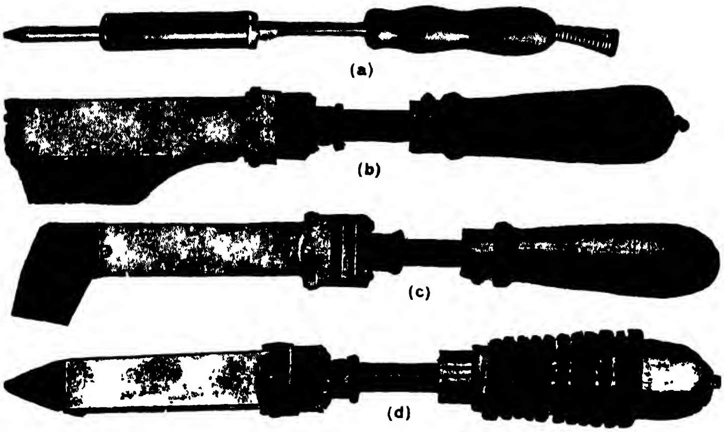
In the first case it is used merely as a means of ensuring perfect electrical continuity, whereas in the second place a certain amount of mechanical strength is given to the joint.

In soldering joints by means of a soldering iron, the iron, when tinned, has a small blob of solder melted on to one of its surfaces (some soldering irons have a small nick cut into them to receive this solder), and the pool of solder is then held underneath the joint in the copper wire which has been previously bathed in flux. Capillary action sucks up the molten solder between the interstices of the joint and solders it solid.

Generally speaking the essence of good soldering lies in the fact that the iron must be perfectly clean and must be well bathed with flux before the solder is applied to the hot iron in order to tin it. Each face of the iron should be tinned, so that there is no copper showing at any point where the final solder is to be applied for the process work. The object to be soldered must be cleaned perfectly in the same manner in the first instance by scraping or filing before the twisted joint is made, and in the second place by flux applied liberally after the joint has been made. It must be emphasized that the cleaning must be really complete before flux is applied. A minute spot of grease or the faintest film of oxidized metal will prevent good soldering. With properly cleaned and prepared surfaces, and an iron at the right temperature, the solder runs easily into the joint and the job is simply, very quickly and neatly done. Excess solder and an overheated iron with dirty surfaces will only make a botched joint. When the joint has been soldered solid in the manner described, it is as well to shake it or dust it over quickly while the solder is still in a molten state to remove any blobs of superfluous metal.

It should be remembered that a well-made joint, particularly in the smaller sizes of cable, should be sufficiently strong before the solder is applied to withstand any stress which may be placed upon it. Soldering in jobs of this sort is not intended to increase the mechanical strength but merely to complete a perfect electrical contact between the copper surfaces to be jointed.

While anyone with a certain amount of practice may learn to make perfect soldered joints of this sort, wiped joints are much more difficult, depending very largely on the correct temperature of the



SOLDERING IRON. Fig. 1 (a) For instrument work such as soldering hair springs; (b) for seam soldering; (c) for filling crevices and butt soldering; (d) for plain work.
Dowsing Radiant Heat Co., Ltd.

metal, and should in general be left to expert plumbers and jointers. When a joint is to be wiped the two surfaces of lead to be jointed should be painted with blacking at a point beyond which it is desired that the wiped joint should not extend. The soiling of the lead in this way prevents the solder taking beyond the desired limit and a clean finish to the wiped joint is achieved.

However careful the workman may be, splashes of solder are apt to be scattered while a joint of any part is being soldered. Care should be taken, therefore, to keep the whole clear of any other electrical conductors or junction boxes where the presence of a few drops of solder might have evil effects.

After finishing a joint any adjacent bare conductors should always be examined for such stray drops of solder.
See Connexion ; Joint.

SOLDERING IRON, ELECTRIC. An iron with an electric heating element embedded in the bolt. Its great advantage is that it is heated, and used, continuously; there is no waiting to re-heat the iron or change it for another hot one when it gets cool. It is, therefore, particularly well adapted to manufacturing work entailing a large number of soldered connexions, *e.g.* telephone apparatus ; in instrument manufacture where delicacy of work is important ; and so forth. The elements are usually of the wound-mica type, and must be firmly clamped in position both to avoid burn-out troubles and to secure good heat transmission. Connecting leads are brought out through the handle, 6 ft. of flexible being the normal allowance for connecting to the supply point.

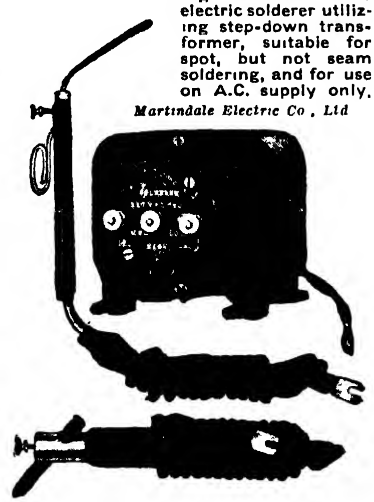


Fig. 2. Martindale electric solderer utilizing step-down transformer, suitable for spot, but not seam soldering, and for use on A.C. supply only.
Martindale Electric Co., Ltd

Electric soldering irons are made in a wide variety of patterns and sizes with bits specially shaped, *e.g.* pointed, hammer or hatchet shape, to suit the particular purpose for which they are required. Light models, $\frac{3}{4}$ to 1 lb. weight, are loaded from 75 to 90 watts, while heavy industrial patterns, weighing $2\frac{1}{2}$ to $3\frac{1}{2}$ lb., may have loadings 300 to 450 watts. The former consume less than $\frac{1}{10}$th unit per hour, and the latter $\frac{1}{3}$ to $\frac{1}{2}$ unit per hour. In industrial applications particularly, provision for earthing is desirable, and 3-core cab tire flexible is commonly used.

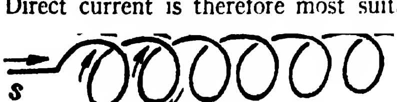
For complete safety step-down transformer fed soldering irons are to be recommended, though the cost, due to the transformer, is considerably higher. The irons can be constructed for operation at, say, 25 to 50 volts, and the transformer ratio selected accordingly. Another form of transformer-fed iron is illustrated in Fig. 2. This comprises a double-wound transformer, and a carbon electrode and solder holder are brought together to complete the secondary circuit, the arc melting the solder at the spot to be soldered. This equipment is especially useful for jig soldering in radio work and the like.

An alternative method of heating soldering irons electrically is provided by a small muffle furnace in which ordinary irons are inserted to be heated. The heating element is contained in a fireclay chamber surrounding the metal tube into which the iron is inserted. Nickel chrome coiled wire heating coils are utilized. Single and twin bolt heaters are made, the former being suitable for coil winding and light assembly and the latter for general assembly work and seaming. *See* Joint.

SOLENOID. A word of somewhat loose connotation which is generally used to describe a helical coil of wire with a central aperture which is used for exciting an electro-magnet, and whose length is considerably greater than its diameter. Such a coil, when carrying direct current, has the properties of a permanent magnet, and the polarity of a solenoid is ascertained by the easily remembered rule that the direction of the magnetic flux is that in which a right-handed screw would move axially if rotated in the direction of the current flow. Thus, if looking at one end of a solenoid the direction of the current is clockwise, the far end of the coil will be a north magnetic pole.

The magnetic reluctance of a solenoid is practically that of the internal core, so that the attractive force on a plunger within this core will be such as to tend to make the plunger take up a position central with respect to the length of the coil. If, however, the solenoid is surrounded by magnetic material, the electro-magnetic force on a plunger will be such as to tend to make the reluctance of the magnetic circuit a minimum.

The solenoid type of electro-magnet comprises a coil in which a plunger moves in response to the electro-magnetic forces of either alternating or direct current. With A.C. the direction of the force is constant, but its magnitude oscillates at double the supply frequency. There is also, with A.C., a loss of power due to the formation of eddy currents, and, possibly, undesirable chattering. Direct current is therefore most suitable



SOLENOID. Fig. 1. How the polarity of a solenoid is determined is shown in this diagram.

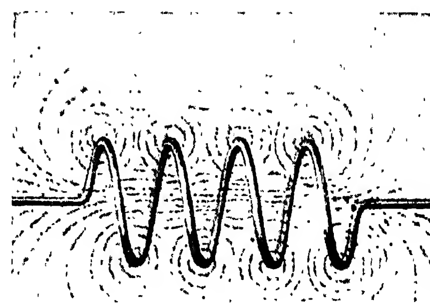


Fig. 2. The lines of force represented above illustrate the magnetic field of a solenoid coil.

for solenoid electro-magnets, and where the supply is A.C. it is not unusual to provide this direct current by means of metal rectifiers (*q.v.*).

Solenoids are used extensively in all patterns of automatic switchgear, and also for protective relays. Remote controlled oil circuit breakers are frequently closed by heavy pattern direct-current-operated solenoids, while a solenoid is invariably used to trip such breakers. Solenoids are also used in many patterns of automatic starting gear for direct-current motors. In the sphere of automatic protective devices we find solenoids used for over-current and under-voltage trips or releases in motor control gear, and also in relays for duty of this kind. *See* Ampère-Turns; Blow-out; Coil; Coupling of Circuits; Flux; Relay, Switch.

SOLID SYSTEM (of Cable Laying). Lead-sheathed and armoured underground cables with paper insulation are now most reliable. The freedom with which such self-contained cables can be transported, laid, lifted and replaced has almost rendered obsolete the solid system of cable laying.

The method is chiefly associated with conductors protected by bitumen, or bitumen compound with or without vulcanized rubber layers of insulation. These cables are laid side by side in a creosoted wood or earthenware trough and run in solid with bitumen. At short intervals on the bottom of the trough are placed supporting bridges of china, hard bitumen compound, or of wood thickly coated with compound. The cables are

run out and carefully laid on these supports clear of the bottom of trough. Choosing a time free from rain or snow, the troughs are carefully filled in with layers of melted bitumen, and then thick tiles are laid as an outer cover over the top. These are held in position by the cohesion of the upper layer of bitumen. Bitumen is a most excellent and very permanent protector against corrosive moisture, and for such places as stable yards and the surface works of mines it well withstands the severe conditions. Obviously, the solid system demands skill and experience to secure good results. Bitumen has a tendency to flow, even at normal temperatures, and is therefore not suited for sloping tracks.

SOUND FILM PLANT IN MODERN PRACTICE

By N. H. Codling, D.F.H., Graduate I.E.E.

This article is in two parts. The first describes the basic principles and general equipment of the most modern sound film reproducing systems. The second describes the individual systems of R.C.A. Photophone, British Thomson-Houston Co. and Western Electric Co. For other aspects of cinema electrical work see Cinema Plant ; Dimmer ; Projector ; Stage Lighting.

Sound film plant is composed of two groups of electrical apparatus used for the production and the reproduction of cinematograph films, accompanied by synchronized sound. The first group, known as the recording plant, simultaneously photographs the scene and records the sound in synchronism, this usually being carried out by a highly qualified staff in the studio. The second group, called the reproduction equipment, projects the picture on to the screen and reproduces the synchronized sound so as to create the illusion that a person on the screen appears to be actually talking, as in the original scene.

Basic Principles

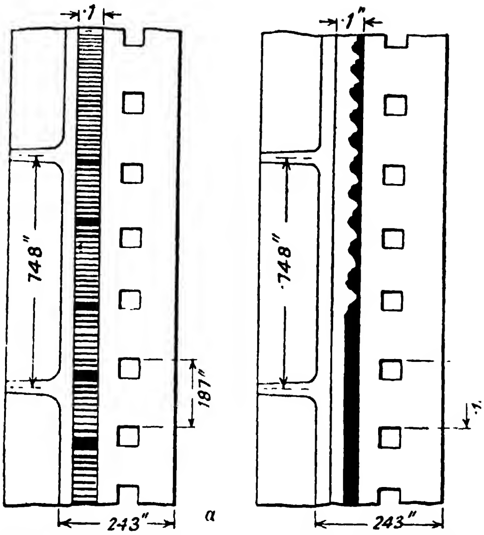
Recording. The various methods of recording of sound are fully dealt with under the heading Recording, and it suffices to state that the microphone currents after amplification are utilized to vary the intensity of either the wax impression on a disc or the intensity of size of a beam of light which is concentrated on to the film passing through the machine at a constant speed of 90 feet per minute, in perfect synchronism with the film photographing in the camera. Thus, the modulated current is converted into a modulated light beam which exposes a narrow strip of the film corresponding to the current from the main amplifier. This strip of ⅛-inch maximum width, and known as the sound track, runs the full length of the film between the picture on one side and the sprocket holes on the other, and a point on the sound track is actually 14½ inches in advance of its associated picture, to allow for the film running through the picture projector prior to the sound head.

In recording on disc (a method rapidly falling into disuse) extra large records are employed revolving at 33⅓ revs. per minute and capable of carrying the equivalent of 1,000 feet of film (*see* Recording).

Reproduction. The film is run through the reproduction apparatus at the same constant speed, and a small beam of light passes through the sound track as it travels through the machine. The sound track modulations vary either the intensity or the amount of light passing through the film according to the type of recording employed, *i.e.* variable density or variable area method. Examples and dimensions of the sound track for the two types are illustrated in Fig. 1.

The modulated beam of light falls on a photo-electric cell (*q.v.*), which converts it into a very weak modulated electric current. This is amplified by a small amplifier, situated close to the cell in order to minimize extraneous noises picked up by the wires carrying the extremely weak current. The current is next passed to a fader (described later), which serves the dual purpose of a volume control and also a change-over switch to connect either of two projectors to the main amplifier.

As far as the sound head is concerned,



SOUND FILM PLANT. Fig. 1. (a) Variable density; (b) variable area, sound track. Overall width of film is 35 mms. Point on sound track is 14·5 in. in front of its associated picture.

it makes little difference which of the two methods of recording has been adopted. Three essential units are incorporated in the sound head, which is usually a three-chambered casting, containing in its respective compartments the exciting lamp and its optical system, the film gate together with rollers and gearing, and the photo-electric cell. Fig. 2 shows the lay-out of the sound head and projector system.

Exciting Lamp. A low-voltage lamp, with a single coil bar filament sufficiently strong to withstand fluctuations in A.C. supply, is used to provide a source of light which is focussed on to the film in the sound gate by means of a lens system. This lens system is sealed by the makers and should not be tampered with save for focussing the light by the adjustment screw provided and occasional cleaning with silk. Perfect focus of the light is required, and therefore the lamp should be kept perfectly clean, and, on occurrence of any discoloration of the surface or sag in the filament, should be replaced by a new one.

Photo-electric Cells. These are fully discussed under their own heading (*q.v.*), but the same necessity for cleanliness applies. Perfect contacts and firm connexions of leads are also essential, the extreme sensitivity of the device rendering it one of the most susceptible and vulnerable parts of the system. Defective batteries or insufficient plate voltage will result in inefficient operation and possible distortion of the sound output. It is clear that the film itself must be kept in perfect condition, as dirt, scratches, dust or oil on the film will affect the modulated light beam falling on the cell window.

Two projecting machines are necessary for the presentation of a continuous programme, since each reel of 1,000 feet of film lasts about eleven minutes, when the sound output must be switched over by means of the fader to the other machine, which has been started up with the next consecutive reel already in position. With care, the operator can effect the change without noticeable interruption of the sound or action of the film, and a continuous programme made up of several reels of film can be projected. Similarly, in the case of sound on disc reproduction the magnetic pick-up transfers the signal modulations on the wax into modulated electric currents, which are led to the fader.

The general lay-out of an installation is shown in Fig. 3.

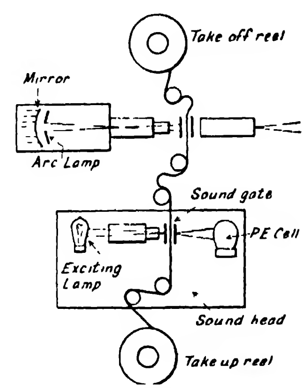


Fig 2. Simplified schematic diagram of sound head and projector.

From this it will be observed that the controlled modulated current on leaving the fader enters the main bank of amplifiers, where means are also provided for switching in non-synchronous equipment, such as is used for providing a musical programme during intervals and for announcement purposes.

From the fader, in both cases, the output is then amplified by means of a voltage or high gain amplifier and finally by means of a power amplifier. The output of the power amplifier is taken to one or more loud speakers, usually situated behind a special type screen, which allows the sound to pass through it into the auditorium and thus give the illusion that the

sound is coming from the source as shown on the screen. A small speaker is used in the operating box by the operators for monitoring purposes.

Amplifiers. The amplifier equipment is usually divided into two parts, namely, the photo-electric cell amplifier previously mentioned, and the main amplifying bank built up in standardized units, according to the size of theatre for which the installation is designed. The circuits followed are those employed in the output stages of radio receivers as described under Amplifiers (*q.v.*), straight circuits, transformer, choke or resistance coupled, followed by push-pull stages, being generally adopted. The amplifiers with their associated equipment are mounted on vertical iron racks (*see* Fig. 4), each unit being enclosed in a metal housing. The main supply switch is usually incorporated on one of these racks or mounted close by.

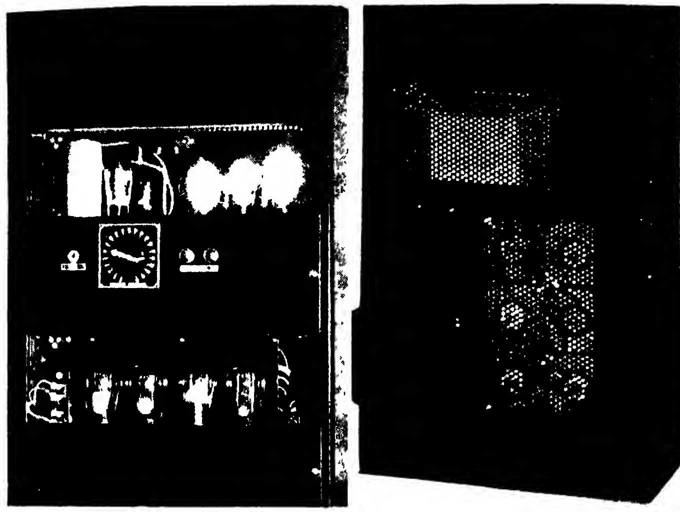
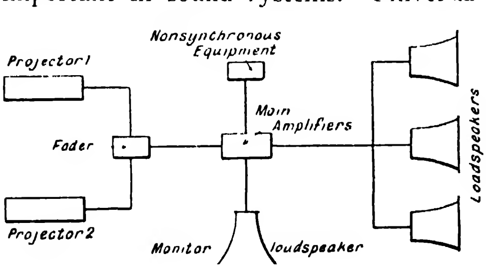


Fig. 4. (a) Top half of reproducing amplifier rack with front plates removed to give access to valves. (b) Rear view of lower half showing resistance elements, etc.

Courtesy of R C A. Photophone, Ltd

Power Supply. In this country several types of power supply are available, each requiring special consideration before it can be adapted to a sound-reproducing system. For D.C. supply, either shunt or compound driving motors fitted with special speed-governing devices are employed, and with A.C. synchronous, induction or repulsion motors. Synchronous motors have the paramount advantage of constancy of speed so important in sound systems. Universal motors suitable for any voltage and frequency are manufactured for the non-synchronous equipment which is usually provided for playing gramophone records during the intervals.



SOUND FILM PLANT Fig. 3. Simplified schematic diagram illustrating lay-out of projectors, amplifiers, loud speakers and non-synchronous equipment.

If the D.C. supply is not of the correct voltage a motor-generator set is installed comprising a motor running on the supply voltage coupled to a dynamo suitable for supplying the projector motors. For A.C. a voltage transformer is all that is necessary. In some cases conversion from D.C. to A.C. or *vice versa* may require a rotary converter set.

Loud Speakers. These are usually of the electro-dynamic coil type and are installed directly behind or at the side of the screen about two-thirds of the way up, it being found, in practice, that this height gives the best illusion. Exponential horns, *i.e.* horns whose areas double at equal intervals along their length, with from 8 to 16 feet of air column, can be coiled up into a space about 4·5 feet square, and are found to have excellent directional and tonal qualities. As many as eight horns may be built up on racks behind the screen, facing in different directions to transmit the sound evenly throughout the auditorium. All the speakers must be matched, however, so that all field coils and voice coils are in phase, otherwise interference will result.

Acoustics. No matter how excellent the reproducing equipment may be, it is of little use when installed in a theatre with poor acoustic properties. Though the design of the theatre comes outside the scope of the projectionist, he can considerably reduce excessive reverberation in a hall by substituting surface materials in convenient positions so that extra absorbing power is attained. Slight alteration of the direction of the loud speakers often effects considerable improvement in the reception for the audience.

The Sound Film. Since a point on the sound track is $14\frac{1}{2}$ inches in front of its associated picture, the film must be carefully threaded so that this length of film is maintained between the picture aperture and the centre of the sound gate aperture. The method of looping the film is indicated in Fig. 2. Six feet of blank film, known as "the leader," are provided for threading purposes, and when this has been run through and the driving motor has attained full speed, the fader is brought up to its requisite setting. Some films are provided with change-over marks, but it is advisable for the operator to work from a cue-sheet, which indicates when to start up the other projector and the instant to switch over, a few seconds later

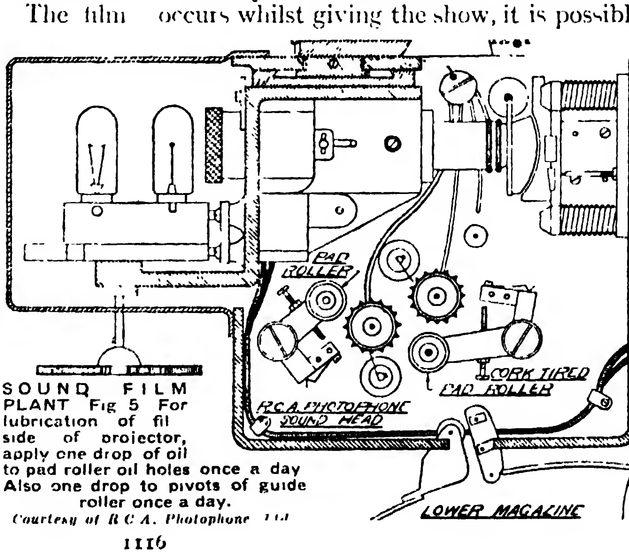
Special care is required in rewinding the film to keep the trailing wheel from overrunning the driven reel. If this occurs or if the tension on the brake is too much, the turns of film will slip and scratch the sound track and the picture. The film should be cleaned during rewinding by holding a clean soft cloth against both sides of the film.

When a break occurs, the sound track requires special treatment. If the tear results in two or three pictures being destroyed, they must be replaced by an equal number of frames of blank film, to maintain synchronism. The sound track is painted over with a half-moon for variable-area recording, and a blunt apex for variable density, black lacquer being used for the purpose. This avoids the sudden "plop" at the joint which would otherwise occur in the loud speakers.

Running and Maintenance. For starting up the show, thread the film as previously described, and close the main supply switch. See that the fader is off and the volume controls at normal setting. Note that the proper aperture plate is in the projector and that the film-disc switch is on to "film." Start the amplifiers, taking care to allow the valve filaments time to warm up before switching on the plate voltages. Turn on the exciter lamps and check the meter readings. See that the lens system is focussed by inserting a white card in the film gate. Strike the projector arc and at the correct time start the projector motor. When the motor reaches normal running speed, open the dowser, and at the cue for starting sound switch in the fader, bringing the volume up to its requisite level. An assistant amongst the audience should be in telephonic communication with the operator to regulate the volume of sound. For stopping the reverse procedure is adopted.

Careful lubrication is essential for trouble-free operation, and manufacturers' lubrication charts should be followed. Fig. 5 shows the various oiling holes and indicates the requisite lubrication for an R.C.A. sound head. The film side of the projector is shown, but similar oiling must be attended to on the opposite or motor side of the projector.

Finally, it may be noted that, if trouble occurs whilst giving the show, it is possible



SOUND FILM PLANT Fig 5 For lubrication of fil side of projector, apply one drop of oil to pad roller oil holes once a day Also one drop to pivots of guide roller once a day.
Courtesy of R C A. Photophone Ltd

to continue the performance by working on the other projector or cutting out a defective amplifier and raising the volume control. In case of film break or other emergency a foot brake is usually provided, but it is important that this should be used only in an emergency.

There are several important systems of sound film equipment employed in this country, all operating, however, on the same underlying principles already discussed.

R.C.A. System

Employs the "variable width" method of recording, the sound record consisting of a uniformly opaque strip of varying width along the sound track. The reproducing equipment is manufactured in many types and only general details can be given here. The type of sound head employed with small theatre equipment is illustrated in Fig. 5. A special impedance roller device takes out ripples or variations in film speed, ensuring that the film is pulled at a constant speed through the film gate. It consists of a flywheel attached to a free roller over which the film passes to the constant speed sprocket.

Motors. D.C. projector motors are supplied fitted with a centrifugal regulating switch which acts on the principle of the governor to cut out resistance, thereby maintaining constant speed. With A.C. supply a motor generator set is used for conversion.

Fader. For change-over from one projector to the other, R.C.A. employ two methods, namely, (a) potentiometer method, (b) relay method. In the former a potentiometer (*q.v.*) is used simply as a change-over device and not as a volume control, whilst in the latter an instantaneous change-over is effected by means of a relay controlled by two two-way switches, one on each projector. Operating either switch actuates the relay. In place of an attenuator, a "compensator," which is a simple variable filter device, is incorporated in R.C.A. equipment. By its means, if a film is weak in its upper frequency range, decrease in the lower frequencies may be effected to obtain a greater balance of tone. Improvements in recording generally render the compensator unnecessary nowadays.

Amplifiers. These are carried on racks, from which all power is obtained for the amplifiers themselves, the photo-cell and exciting lamp circuit, and the monitor and stage speakers. The apparatus is made up of a number of self-contained units, independent of one another for power supply. In common with other systems they consist essentially of a voltage amplifier followed by a power amplifier, screen-grid transformer coupling being employed. A special input jack is also provided for the connexion of a non-synchronous turn-table or other special circuit. These amplifier racks are designed for A.C. 110-volt 50-cycle supply, and in D.C. districts a D.C. to A.C. rotary converter is required. Loud speaker field supply and exciting lamp supply panels are incorporated on the amplifier racks.

Loud Speakers. These are of the electro-dynamic cone type, consisting essentially of a specially designed six-inch cone, a 100-volt field, and a special throat arrangement with a four-inch square opening, which matches the opening of the directional baffle to which it is fitted. Three types of directional baffles are available, namely, the 37-inch, the 5-foot, and the 10-foot baffle. The latter was designed to give uniform response over the entire range of audible frequencies, permitting uniform and equal reproduction from 40 to 10,000 cycles.

High Fidelity Equipment. This equipment is designed to reproduce a frequency range from 40 to 10,000 cycles and to give a more life-like and natural reproduction than that obtainable with ordinary equipment. The modifications necessary to achieve these results include the use of a special ribbon microphone for recording, improved amplifier and mechanical design, elimination of the sound gate and its replacement by a smooth drum with free loops of film on either side, and the development of a loud speaker unit which when driving into a suitable directional baffle has a smooth response from 40 to 10,000 cycles operating at a relatively high efficiency.

Troubles. The R.C.A. provide charts with their equipment enabling troubles to be quickly and easily located.

For convenience they are given in tabular form below:

1. No sound.

(a) Film-disc switch or fader off
(b) Exciting lamp reads zero when turned on. Lamp burned out or not turned in position.
(c) Exciting lamp lights but no light at P.E. cell. Sound-gate aperture clogged.
(d) No sound from photo-cell of either projector, but sound on disc. Defective photo-cell or open photo-cell polarizing battery leads

2. Poor quality.

(a) Poor film.
(b) Dirt on film, sound gate or sprocket
(c) Defective photo-cell
(d) Sound gate open.
(e) Worn sprockets.
(f) Damping device out of adjustment.

3. Unequal volume from projectors

(a) Weak photo-cell.
(b) Poor exciting lamp
(c) Dirty sound gate.
(d) Unmatched photo-cells or exciting lamps.

4. Noises

(a) Noisy photo-cell battery.
(b) Voltage too low.
(c) Guide rollers out of adjustment.

5 Distortion.

(a) Optical system out of focus.
(b) Oil in lens assembly.
(c) Cracked lens, etc.

These charts are also applicable in many respects to other types of equipment

British Thomson-Houston Co.'s System

This equipment is specially designed for simplicity of operation and maintenance. Battery supplies have been eliminated and switches limited as far as possible. A motor generator set supplies 110-volt D.C. to the two projector motors and the loud speaker fields and to the D.C. side of a rotary converter, which feeds 110-volt A.C. to the amplifiers. A small 12-volt D.C. generator coupled to the main set supplies the exciting lamps.

Centrifugal speed control ensures very close speed regulation, and the motor drives the projector through a gear-box which reduces the speed of rotation from 1,800 to 800 r.p.m. The turn-table drive is taken through a tubular rubber coupling to the turn-table gear-box which reduces the speed to 33⅓ r.p.m. by means of a "floating" worm reduction gear.

Sound Head. Consists of a three-chambered casting, the first chamber holding three exciting lamps on a turn-table, the second the optical system in which is created the image of the slit, and the third a Mazda calcium gas photo-electric cell and the cell transformer, which steps down the output to match a low impedance line, the output going straight to the fader. Calcium cells give a very large output and the preliminary amplifier is unnecessary.

Amplifiers. These are standardized according to A.C. output, type B of 40 watts output being suitable for halls of 1,000–3,000 seating capacity, and type C of 10 watts output for small theatres. The amplifiers are housed in metal cabinets which contain everything in duplicate. Three-stage amplification is employed, and in type B the output valve has 1,000 volts on the plate. Interlocking safety switches are incorporated to break circuit if the door of the cabinet is opened.

Fader. A potentiometer type change-over fader is employed.

Loud Speakers. Each amplifier feeds four loud speakers of the moving-coil type mounted with Sindanyo baffle-boards. The speakers may be mounted to suit the acoustics of the hall, and very little back stage space is required.

B.T.P. Equipment

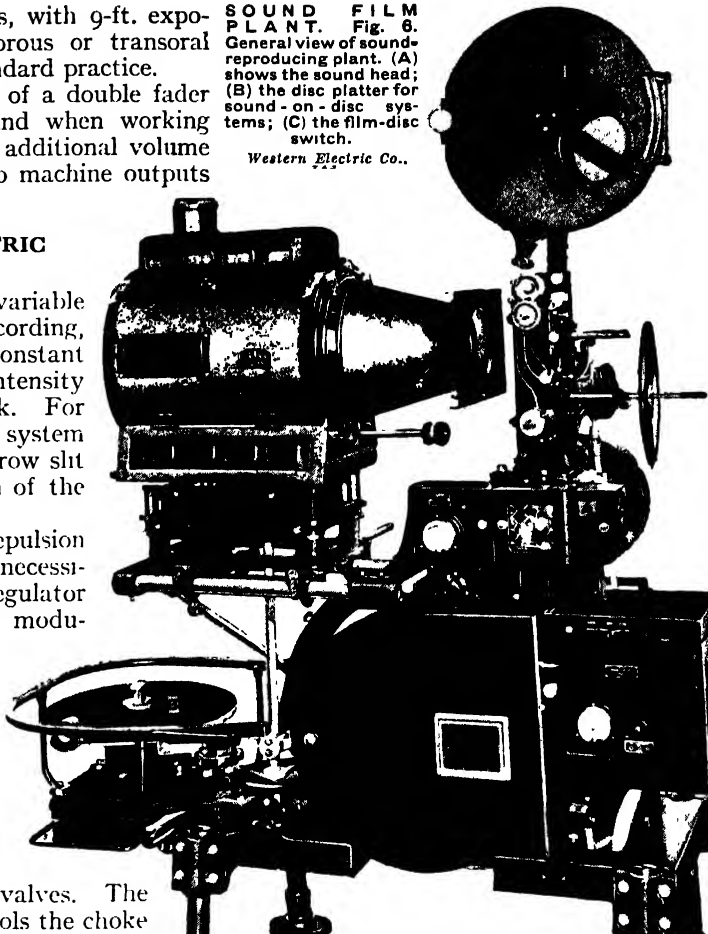
This is very similar to the B.T.-H. Both film and disc reproduction are provided for, the disc turn-table and synchronous motor being on separate heavy pedestals running parallel with the length of the projector stand. A vertical shaft, driven through a reduction gear-box, drives the projector head directly from the motor shaft.

The sound head is provided with duplicate exciting lamps. The first stage amplifiers are mounted on the wall of the operating box, in front of the projectors, the outputs from the photo-cells being connected to these amplifiers by means of flexible cables. The main amplifier stands in a metal case in a suitable part of the operating box. The output stage is arranged for 75 watts dissipation, having first and second stages fed by batteries, but smoothed D.C. from the generator feeds the output stage. The equipment is complete with a three-machine motor generator set on one bedplate, driven by the available supply. The first generator has two commutators, and provides high tension on one, and low tension for battery charging on the other. The second generator is a 3-phase, 45-volt, 25-cycle alternator which gives supply for the 3-phase projector

motors. Horn speakers, with 9-ft. exponential horns, and porous or transoral screens are used as standard practice.

Control is by means of a double fader and tone controller, and when working with sound-on-film an additional volume control enables the two machine outputs to be equally matched.

SOUND FILM PLANT. Fig. 6. General view of sound-reproducing plant. (A) shows the sound head; (B) the disc platter for sound-on-disc systems; (C) the film-disc switch.
Western Electric Co.



Western Electric Equipment

Employs the "variable density" method of recording, giving a strip of constant width but varying intensity along the sound track. For this reason the optical system is provided with a narrow slit which limits the width of the light beam.

Motors. A.C. repulsion motors are adopted, necessitating a special speed regulator known as a magnetic modulator. This consists of a small motor alternator set whose frequency depends on the speed of the motor. The rotor feeds one side of a transformer, whose other winding is fed with D.C. from two half-wave rectifier valves. The D.C. current flow controls the choke effect of the transformer and so the torque of the rotor. The valve emission thus controls the motor speed.

Fader and Amplifiers. The fader is of the double potentiometer centre zero type. The amplifiers are mounted on a rack as in other systems, together with the switch for non-synchronous reproduction, and an output control panel for switching in individual loud speakers. Auto-transformer tappings enable impedance matching to be maintained.

Loud Speakers. Moving-coil exponential horn speakers are employed, with a 12-volt field. From one to three horns, each of 14 feet developed length, are used, depending on the requirements of the auditorium.

The horns are constructed of wood or metal, and are so folded as to occupy a space only 4½ feet square. The receiver unit diaphragm is cup-shaped in the centre to give the diaphragm extreme rigidity. From one to four receiver units may be used with each horn, and one to three horns may comprise an installation.

Batteries. A charging panel located near the batteries enables an auxiliary set to be charged, whilst one set is in operation. Tungar bulb rectifiers or motor generator sets are provided for charging.

Wide Range Equipment. A special equipment now increasingly used for reproducing a wider range of frequencies than the standard equipment. Special high- and low-frequency horns are provided, and the outfit is modified to include a special filter circuit to supply the respective units with high, middle and low frequencies. Improved amplifiers, sound gates and lens units are adopted.

SPACE CHARGE. A charge not actually carried by a conductor. In a thermionic valve, the current passing between the anode and cathode consists of a stream of electrons emitted by the hot cathode or filament and attracted to the relatively positive anode. Now each electron is itself a minute charge of negative electricity, and the resultant negative charge represented by all the free electrons in the inter-electrode space is the space charge.

The presence of this space charge in a diode, for instance, has a marked influence on the flow of electrons and on the performance of the valve in general. Since like charges of electricity repel each other, it follows that those electrons which have departed from the cathode and are being accelerated towards the anode exert a repulsive force on those just leaving the cathode, and for this reason many are driven back again to the cathode. With low values of anode voltage nearly all are driven back, and practically no anode current flows.

In an amplifying valve a control grid in the form of an open wire mesh is interposed between cathode and anode, and the field due to the space charge is modified to an extent depending on the potential applied to the grid. In this way the anode current is controlled by variations of grid voltage, and the amplifying properties of the valve are based upon this principle. *See* Grid; Valve.

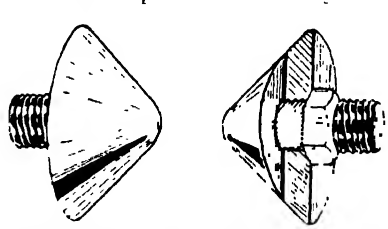
SPACE FACTOR. The ratio of the amount of actual copper conductor in an armature slot, to the total space occupied by conductors and insulation. This ratio obviously decreases with the amount of insulation required, *i.e.* the higher the voltage the less the space factor. The average value for a modern 200-volt generator would be of the order of 0·7 or 0·75. *See* Slot.

SPARK. A variety of sparks is here listed and defined. They include Active, Arcing, Break, Disruptive, Jump, Make, Musical, Pilot, Quenched, Singing, Timed, and Trigger and Wipe sparks.

An active spark is oscillatory and an arcing spark is a continuous discharge across a gap and not a succession of separate active sparks. A disruptive spark is one occurring through a dielectric (*see* Puncture Strength), and a jump spark is one that may precede a main discharge, or that takes place between conductors not usually provided for that purpose. Break and make sparks occur at the hammer contacts of an induction coil (*q.v.*), the break spark being more intense than the make. Musical or singing sparks occur in certain forms of arc discharger transmitters. A timed spark is such as that used in motor car ignition (*q.v.*). For quenched spark see that heading. A pilot spark is a spark occurring in advance of a main spark, serving to break down the gap resistance. The trigger and wipe sparks are other names for pilot spark.

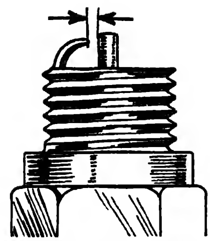
SPARK GAP. A gap across which it is desired to produce sparks. Three main uses exist for these gaps, *i.e.* wireless transmission and certain diathermy (*q.v.*) apparatus, some electric furnaces (*see* Northrup Furnace) and in motor car ignition (*q.v.*). Gaps are also used as protective devices against surges in line and delicate circuit networks, in magnetos and in H.T. induction generators.

Function of the Gap. For deliberate spark production, it is customary to use spherical or semi-spherical electrodes. Alternatively, the main gap may consist of a series of small gaps between separating mica plates. The gap is then known as a quenched gap as used in spark transmitters and diathermy equipment. The function of a spark gap is to allow a charge to be impressed upon a condenser. The gap width is adjusted to correspond with the maximum safe charge the condenser is capable of sustaining. When this charge has been built up, the air or gas insulation between gap electrodes breaks down, a spark occurs and the condenser discharges. The width of the spark gap must be such as to prohibit arcing between the electrodes. If circuit constants are favourable, the discharge will be oscillatory (*see* Oscillatory Discharge) and will be sustained until the gap



SPARK GAP Fig. 1. Electrodes for spark gaps are of various shapes and designs. Here is a pair of conically shaped electrodes.

potential falls to a level where even the ionized gas or air path between electrodes has too high a resistance to allow further sparks to pass. About 4,600 volts are required to produce a spark across 1 millimetre in air, but there is not a directly proportional relationship between gap length and breakdown voltage, which depends upon electrode size, air pressure, humidity, etc.



SPARK GAP. Fig. 2. Gap between electrodes of sparking plug across which spark occurs.

Gap Shape. Plain discharge gaps must be spherical because high-tension electric charges tend to dissipate from points, and there would be risk of full charges not being built up. Conversely, gaps used for safety purposes are naturally made pointed, for early charge dissipation is sought. The motor car sparking plug, however, through its smallness and low power of spark energy, has one pointed electrode, as shown in the figure. This gap should be ·025 or $\frac{1}{40}$ in. for coil ignition systems, while for magneto ignition ·020 or $\frac{1}{50}$ in. is suitable. Too great a gapintroduces starting difficulties, and too small a gap may result in sooting or in oil bridging the plug points.

In many cases where spark gaps are used in a positive sense, to allow high-tension charges to build up, it is customary to provide a safety point gap. This gap is fixed in parallel with the main gap and adjusted to provide a safety discharge in the event of the main gap being too wide. Absence of a safety gap in such circumstances might cause a condenser breakdown.

Sparking across air-gaps produces the poisonous gases, nitrous and nitric oxide and ozone. These gases have harmful effects upon insulation, especially rubber. *See* Horn Gap Arrester; Puncture Strength.

SPARK GAP FURNACE. The modern high-frequency induction furnace is usually either of the spark gap or thermionic valve type (*q.v.*). The former employ high-frequency currents generated by charging and discharging condensers. Their more important applications include high temperature research work, commercial melting of the rarer metals, making special alloys, and melting and heating in vacuo.

A large range of frequencies may be obtained by altering the size of the furnace coil, and the standard Ajax Northrup equipment includes a special oil-cooled transformer to step the voltage up to that required for charging the condensers, spark gap, safety gaps, etc. The non-rotating spark gap is so designed that a quick cut-off is obtained at whatever part of the cycle the discharge takes place. It is practically silent, and the power expended in it is reduced to a minimum. *See* H.F. Furnace; Northrup Furnace.

SPARKING AND SPARK DISCHARGE. The discharge of electricity through a path which is normally non-conducting.

Sparking may be accidental as in the failure of an insulator, or intentional as in the sparking plug (*see* Ignition).

The term is also used to describe the arc that is formed when opening a switch that is carrying current, and at the brushes of a dynamo on load.

Sparking may be due to the application of voltage to a conductor greater than the surrounding air can stand. On a high voltage overhead line there is an electric field surrounding the conductor. If the strength of the field is excessive, instead of a perpetual spark discharge there may be a corona discharge (*q.v.*). The insulators supporting the line are subject to a strong electric stress across their surfaces, and if they are allowed to become dirty there may be a continuous stream of sparks across their surface. If the insulation is lowered excessively, as it may be by the deposit of soot or salt, it breaks down completely. This is termed a flash-over (*q.v.*).

If the insulation of a conductor has cavities within it, there may be continuous ionization or a minute spark discharge across them. This leads to deterioration of the insulating material, and great care is taken in the design and manufacture of cables (*q.v.*) and condenser type bushings (*q.v.*) to ensure that any cavities are filled with oil or compound.

Sparking at switch contacts occurs when a current flowing through an inductive circuit is broken. If the current circulating in a field coil is interrupted, the collapse of the magnetic field generates a voltage which tends to keep the current circulating. This extra E.M.F. is gener-

ated as the contacts of the switch are just beginning to part. The heat produced is sufficient to melt and vaporize a part of the metal at the surface of the switch which forms an arc (*q.v.*) that may persist even with the switch wide open. Special means are therefore provided for suppressing the arc (*see* Circuit Breaker).

The sparking at the brushes in commutators and the means of suppression are described under Brushes and Commutator.

SPARK-OVER TEST. *See* Flash-Over.

SPECIFIC CONDUCTANCE (or Conductivity). The reciprocal of specific resistance or resistivity, measured in mhos per cubic centimetre.

SPECIFIC CONDUCTANCE OF METALS AND ALLOYS

Material	Mhos per cm cube
Silver (annealed) ..	0·708 × 10^6
,, (hard drawn)	0·61 — 10^6
Copper (annealed) ..	0·64 — 10^6
,, (hard drawn)	0·61 — 10^6
Gold (hard drawn)..	0·45 — 10^6
Aluminium (annealed)	0·38 — 10^6
Zinc	0·173 — 10^6
Brass	0·138 — 10^6
Iron	0·11 — 10^6
Platinum	0·091 — 10^6
Nickel	0·081 — 10^6
Tin	0·076 — 10^6
Lead..	0·049 — 10^6
German Silver ..	0·047 — 10^6
Platinum Silver ..	0·0317 — 10^6
Platinoid	0·0239 — 10^6
Manganin	0·0238 — 10^6
Manganese Steel ..	0·0147 — 10^6
Reostene	0·0127 — 10^6
Mercury	0·0106 — 10^6

SPECIFIC GRAVITY. Ratio between the weights of equal volumes of any substance and of some other substance that has been chosen as a standard of comparison. The substance chosen for comparison as the standard for gases is hydrogen or air, and for liquids and solids water. The specific gravity of a substance is usually determined at some standard air pressure and temperature. Water, for example, is at its maximum density at 4° C., and specific gravities of solids and liquids, therefore, are usually taken at this temperature.

Specific gravities of liquids and solids are generally determined by making use of the fact that a solid floating or immersed in a liquid loses weight equal to the weight of the liquid displaced. The solid is weighed in air and water by means of special balances, and from this the specific gravity may be obtained. A hydrometer (*q.v.*) may be used for liquids. Many special hydrometers are made for certain groups of liquids, as one hydrometer cannot be made sensitive enough to give the specific gravity of any liquid.

The following table gives the S.G. of common substances in daily use:

Aluminium	2·6
Antimony	6·71
Brass	8·1
Copper	8·79
Glass	2·89
Iron (cast)	7·5
Iron (wrought)	7·74
Lead	11·35
Mercury	13·6
Nickel	8·9
Platinum	21·5
Silver	10·47
Steel	7·29
Zinc	7·19
Graphite	2·33
Accumulator acid	1·25

The specific gravity of accumulator acid varies, however, according to the type of accumulator and the state of charge, the limits being approximately 1·110–1·280.

SPECIFIC INDUCTIVE CAPACITY. The ratio of the inductive capacity of a medium to that of air, or, more strictly, a vacuum. It is another name for dielectric constant, the specific inductive capacity of air being taken as unity. *See* Dielectric; Dielectric Constant.

SPECIFIC RESISTANCE. Resistance of an inch or centimetre cube of a conductor between opposite faces. The specific resistances of substances are tabulated usually at 0° C., since resistance changes with temperature. When the specific resistance of a conductor is known, its total resistance can be calculated from the formula $R=\rho l/A$ where R is the resistance required, ρ is the specific resistance, l the length of the conductor, and A its cross-sectional area.

Since wires are circular as a general rule in cross-section, the formula may be written $R=\rho l/{\cdot}7854d^2$, where d is the diameter.

The resistance R is measured in ohms per inch or centimetre cubed, l is the length in inches or centimetres, and A the cross-sectional area in square inches or square centimetres.

Resistance varies with temperature, and the specific resistances of pure metals

increase with increase of temperature. For general purposes the resistance with increase of temperature may be calculated from the formula $R_1 = R\ (1+at)$ where R_1=required resistance.

R = resistance at 0° C. as given by the table.
t = temperature above 0° C. in degrees.
a = coefficient depending upon the metal, and assumed constant for each degree of temperature between the temperatures for which the calculation is made.

Full tables of the specific resistance and temperature coefficients of the various metals and alloys are given under the heading Resistance. *See* Mass Resistivity.

SPEECH AMPLIFICATION. *See* Low-Frequency Amplification.

SPEED CONTROL (of Motors). D.C. Motors. Fractional horse-power motors usually have their speed regulated by a series resistance, cutting down the voltage applied to the machine. This method is also applicable to universal motors, such as those used on desk fans and sewing-machines. If this method were applied to larger machines, a large amount of energy would be wasted in heat in the resistance. On shunt-wound machines speed control is usually accomplished by varying the field strength by means of a resistance connected in series with the field winding only. This method necessitates the use of interpoles on all but the smallest machines, in order to ensure good commutation at all speeds.

The usual method used on series machines is to weaken the field by means of a diverter (*q.v.*). This is a variable resistance connected in parallel with the field winding, so that some of the armature current flows through this resistance instead of through the field coils, thus weakening the field. It is essential that a series motor used for traction should have a wide range of economical speed. In this case, therefore, as two or more driving motors are nearly always used, slow running is obtained by having the motors connected in series, and fast by connecting in parallel, while the highest speeds are obtained by a diverter.

Compound-wound (*q.v.*) motors can have speed variation produced by a shunt-field resistance as in the shunt machine, or a series field diverter as in the series machine, or by both together. A number of special methods are in use, the underlying principle of them being to apply a variable voltage to the armature, the field excitation being constant. This necessitates the provision of a special generator for each motor, thus increasing the cost considerably. A system of this type is the Ward-Leonard (*q.v.*).

A.C. Motors. Wound rotor induction motors can have their speed varied over a small range by inserting resistance in the rotor circuit, but the method is not very satisfactory. On larger machines, either of the wound or squirrel-cage rotor types, speed variation can be obtained by changing the number of poles produced by the stator winding. This method will only produce two or three fixed speeds, and not a range of speeds.

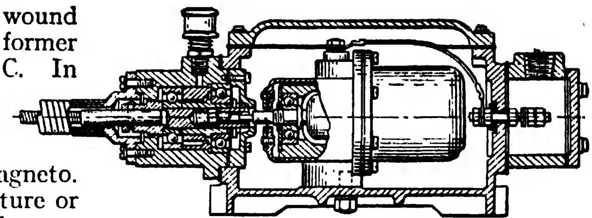
A.C. series motors can be controlled in the same way as D.C. series machines, or by means of a tapped transformer, this method being also applicable to commutator motors with shunt characteristics. The speed of this latter type of motor, and of repulsion motors, may be controlled by altering the brush position.

Many methods of coupling mechanically two motors connected in cascade have been used, *e.g.* the rotor of one connected to the stator of the other for induction motors. Combinations of induction motor and commutator motor have also been developed to give a wide range of speeds, but the applications of these methods are limited to special requirements. *See* Motors.

SPEED INDICATOR. Speed indicators are of use in many types of machine. The advantages of the electrical type of indicator over the mechanical forms are that readings can be indicated at any point within a distance of a few miles of the place at which the machine is situated; over-running produces little harm; an evenly divided scale can also be obtained, with fair accuracy at the lower end.

Magneto Type. This instrument consists of a small magneto-generator coupled to the apparatus whose speed is to be indicated, and a voltmeter, installed at any required point. The voltage produced by the generator will be proportional to its speed, and the voltmeter scale is calibrated in the units required.

The generator itself can be either wound armature or inductor pattern, the former only being used for generating D.C. In this case the commutator is made of special hard wearing material. The field is produced by permanent magnets, thus giving rise to the name magneto. The maximum speed of the armature or rotor is usually between 1,500 and 2,000 r.p.m., a gear drive being incorporated in the generator casing.



SPEED INDICATOR. Magneto type for flexible shaft drive.
Weston Electrical Instrument Co., Ltd.

The D.C. type will also indicate the direction of rotation, but the A.C. generator is more robust, and is used either in conjunction with a rectifier and D.C. voltmeter or a vibrating reed indicator.

Eddy Current. If a copper disc is rotated between the poles of a magnet, eddy currents are produced in the disc tending to stop the rotation, and if the magnet is free to rotate it will be dragged round with the disc. By fitting a spring to hold the magnet back, it will only be displaced by an amount proportional to the speed, so that a pointer would indicate the speed on a suitably calibrated scale. Such indicators cannot be used for telemetering, but are chiefly used as speedometers.

SPHERE GAP. *See* Spark Gap.

SPIDER: ARMATURE, COMMUTATOR. *See* Commutator Spider.

SPILL CURRENT. The current which appears in the relay of a differential protective circuit of the Merz-Price (*q.v.*) type when there is a fault in the main circuit protected. As long as the currents in the primaries of the two current transformers are equal, the secondary currents simply circulate between the two secondary windings. If a fault causes a difference between the two secondary currents, this difference is said to spill into the relay branch of the secondary circuit.

SPINNER MOTOR. A variable speed polyphase induction motor of the cascade type. It is not used except for special purposes requiring a high power drive at variable speed such as ship propulsion.

The motor is provided with a rotor like an ordinary induction motor (*q.v.*). The rotor shaft drives the ship's propeller (or other mechanical drive). The stator under the influence of which the rotor moves can itself be rotated. It is driven by the rotor of a second induction motor to which it is rigidly coupled. That is to say the stator of the first motor is built in one piece with the rotor of the second. The stator and rotor combination is called the spinner. Both fixed and moving stators are supplied with current from the main supply, the moving stator being fitted with slip-rings for current collection.

The fixed stator has a different number (usually greater) of poles from the moving stator Clutches are provided so that the spinner may either be locked to the fixed stator or to the rotor, or it may be allowed to run free. If the fixed stator is wound for N poles and the spinner stator for M poles, and if the frequency of supply is 50 ∿, the following speeds are available:

(1) The spinner is locked to the rotor. The rotor then turns at the same speed as the spinner:

$$\frac{3000}{N} \text{ r.p m. less slip.}$$

(2) The spinner is locked to the stator and current is supplied to the slip-rings only. The speed of the rotor is then:

$$\frac{3000}{M} \text{ r.p.m less slip.}$$

(3) The spinner is allowed to rotate. Current is supplied to the stator and to the slip-rings. If the spinner winding causes a rotating field in the same direction as the stator, the resultant motor speed will be

$$\frac{3000}{N} + \frac{3000}{M} \text{ less slip.}$$

(4) As (3), but with the spinner field rotating in the opposite direction, the speed will be

$$\frac{3000}{N} - \frac{3000}{M} \text{ less slip.}$$

Reversed rotation can be obtained at all the four speeds.

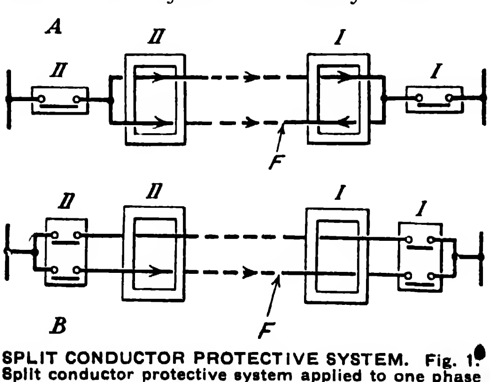
SPLICED JOINT. Term sometimes applied to any joint by which one piece of cable, whether of single or many strands, is joined to another piece of cable. In its proper sense, however, it refers only to one

category of joint in which the strands of the cable to be joined are splayed out into a brush formation and are then intermeshed with one another, the individual strands from one cable being thereafter usually bound round all the strands of the other cable in a closely pitched spiral. The joint after being thus made is usually soldered solid.

From time to time various systems of splicing cable are developed, but generally speaking the term may be used to cover any system of jointing in which individual strands are in the first place separated out and are subsequently intertwined with one another after the fashion of splicing rope.

SPLIT CONDUCTOR PROTECTIVE SYSTEM. The use of current or voltage balance protection such as the Merz-Price system and others (*see* Protective Devices) makes it necessary to instal a number of pilot wires along the whole length of the line which is to be protected. Such pilot wires have certain disadvantages; in the first place they are expensive, secondly they are liable to breakdown, and a fault on a pilot wire may result in interruption of supply; this is particularly the case where pilots are strung on the same towers as the main conductors. Any accident to the latter is not unlikely to result in the pilot wires being affected also. The object of split conductor protection is to obtain current balance protection without the use of pilot wires.

In the split conductor system each main conductor is split into two conductors which are lightly insulated one from the other The system is mostly used for



SPLIT CONDUCTOR PROTECTIVE SYSTEM. Fig. 1. Split conductor protective system applied to one phase of a feeder. *A*, without split switches; *B*, with split switches. The arrows indicate the flow of current the instant after the switch *I* has been tripped by a fault *F* in its vicinity.

cable feeders, and there are three methods of making such split core cables. Each core may be divided into two D-shaped cores; alternatively each double core may consist of a circular conductor surrounded by a concentric annular conductor (split concentric conductor cable). Finally, a six-core cable with six similar round or sector-shaped cores may be used. If split concentric cable is used the inner and outer conductors must be transposed at each joint in order to maintain the balance between the two.

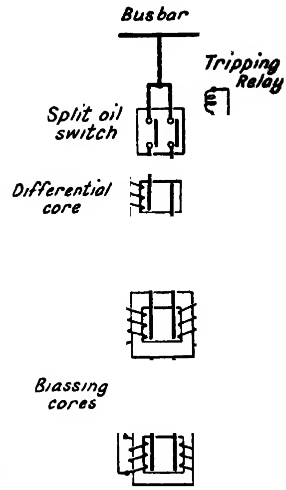


Fig. 2. Application of biassing to one phase of a split conductor protective system.

If everything is properly arranged the currents in each half of each phase will be equal and will balance one another. If now each half of each conductor be led in opposite directions round the core of a current transformer (Fig. 1, *A*), no flux will be induced in it. If a fault occurs it is bound, in the first instance, to affect one half of a split phase before the other, thus unbalancing the currents and causing a flux in the core of the transformer. This induces a current in a secondary winding and trips the circuit breaker.

In order to secure the best operation of split conductor protection it is necessary to carry the split through to the bus-bar side of the circuit breakers (Fig. 1, *B*), *i.e.* provide each phase of the circuit breaker with two sets of contacts. The reason for this can be seen by reference to Fig. 1, *A*. A fault is supposed to occur near switch *I*. The current through one half of the winding of transformer *I* reverses and trips switch *I*. Supposing that the switches are not split, the currents through transformer *II* do not reverse because both halves of the phase continue to supply the fault; they do, however,

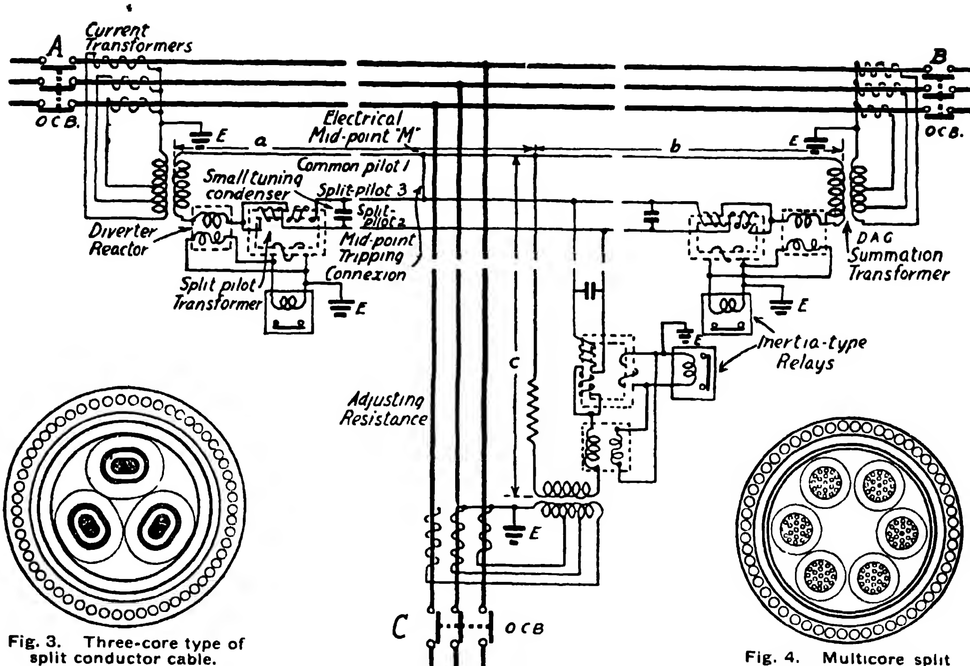


Fig. 3. Three-core type of split conductor cable.

Fig. 4. Multicore split conductor cable.

SPLIT PILOT PROTECTIVE SYSTEM.
Fig. 5. E.H.V. system for a teed feeder using solid core type current transformers on the phases, and a D.A.G. summation transformer

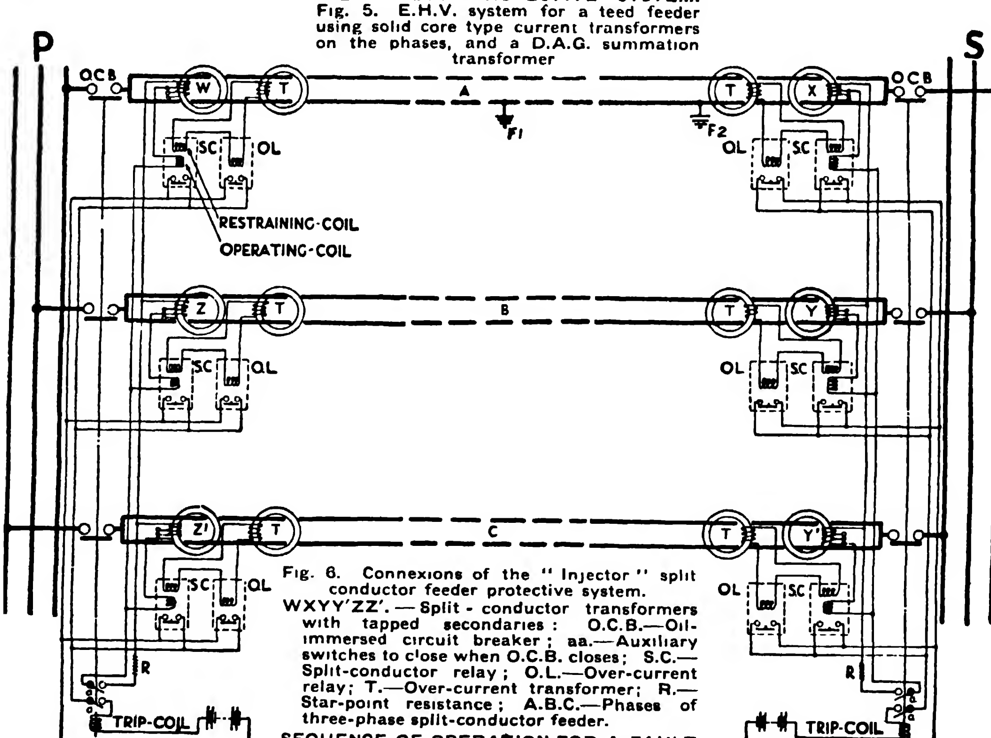
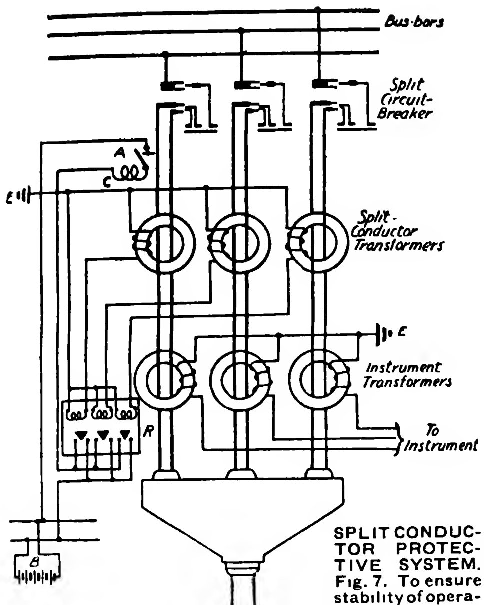


Fig. 6. Connexions of the "Injector" split conductor feeder protective system.
WXYY'ZZ'.—Split-conductor transformers with tapped secondaries: O.C.B.—Oil-immersed circuit breaker; aa.—Auxiliary switches to close when O.C.B. closes; S.C.—Split-conductor relay; O.L.—Over-current relay; T.—Over-current transformer; R.—Star-point resistance; A.B.C.—Phases of three-phase split-conductor feeder.

SEQUENCE OF OPERATION FOR A FAULT AT F (POWER FED FROM P): Transformers W and X simultaneously energize their respective S.C.s.; O.C.B.s at P and S open.

SEQUENCE OF OPERATION FOR A FAULT AT F_2 (POWER FED FROM P): Transformer X energizes its S.C.; O.C.B. at S opens; Transformer X injects into transformers Y and Y'; Current circulates in split-conductor loops of phases B and C; Transformers Z and Z' energize their respective S.C.s; O.C.B. at P opens.

A. Reyrolle & Co., Ltd.



SPLIT CONDUCTOR PROTECTIVE SYSTEM. Fig. 7. To ensure stability of operation, split circuit breakers are employed at each end of the split conductor cable. These circuit breakers have ordinary contacts on the bus-bar side and double contacts insulated from each other on the feeder side as shown.

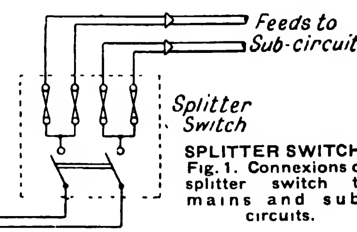
Reyrolle & Co., Ltd

become unequal by an amount depending on the impedance of the transformers. If this be large the unbalance may be sufficient to cause tripping. If, however, the switches are split (Fig. 1, *B*), once switch *I* is open the whole of the leakage current must flow to the fault through one winding only of transformer *II*, so that switch *II* is tripped with certainty.

Biassing may be applied to split conductor protection by connecting the secondary of the differential core to the trip relay by biassing cores, which are traversed by the main conductors (Fig. 2). The biassing is produced by the load current altering the saturation of these cores (*see* Protective Devices, page 971, for action of biassing transformer). *See* Network; Protective Devices.

SPLIT PHASE. *See* Phase Splitting Device.

SPLITTER SWITCH. An appliance for small house wiring installations which combines the functions of the main switch, main fuses, and distribution board which, till recently, were installed as separate components. The splitter switch comprises a double-pole main switch, and two pairs of fuses, contained in a cast-iron case, usually with some interlocking device whereby the case cannot be opened till the switch is in the off position. Fig. 1 illustrates the application of the switch, providing four paths to sub-circuits from the double-pole main switch, each path having its own fuse. Fig. 2 shows a typical splitter switch with cover open, and the four fuses can be clearly seen. The two circuits provided for by the splitter switch have been found by experience to be ample for the great majority of small dwelling houses. *See further* notes on its application under the heading Distribution Board; *also* Fuse.

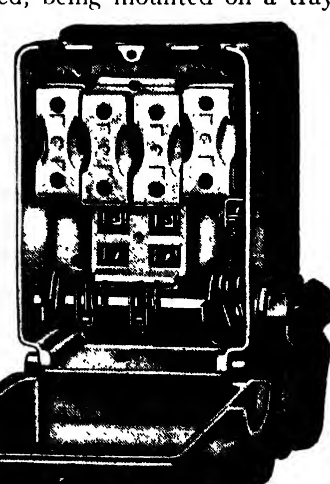


SPLITTER SWITCH. Fig. 1. Connexions of splitter switch to mains and sub-circuits.

SPOTLIGHT. A piece of lighting apparatus designed to project a narrow beam of light (*see* Floodlight). The spotlight is a member of the projector group (*see* Projector) and employs in its more usual forms a very simple optical system. It consists of a housing, in the front of which is mounted a plano-convex lens (known as a condenser); centred behind the lens is a gasfilled projector lamp. The distance of this lamp from the lens can be varied, being mounted on a tray,

Fig. 2. "Sandalite" splitter switch capable of dealing with 20 amps. continuously.

Sanders, Ltd



operated by a knob underneath, or some similar means. The lens condenses the light from the filament into a beam, and if the lamp filament is situated at the focus of the lens, the image of the filament is projected. As the lamp is moved forward, so the image is put out of focus until the lantern gives a circle of light (spot) in which the filament image is barely distinguishable. As the lamp is further moved forward, the spot becomes larger, until a narrow angle flood is obtained free of any filament image.

The spotlight lamphouse is generally made of such a length that the lamp is stopped before it reaches a point where the filament image is objectionable. As an aid to efficiency, a spherical reflector is generally fitted at the back of the lamp so that the filament is in the focus of the reflector. Thus a certain amount of light is reflected back through the filament to the lens. This reflector is set in a fixed position by the manufacturers; a slight adjustment is provided for the lamp-holder to allow for variation in filament height. The other forms of reflector, mangin and parabolic, are not suitable for this purpose.

The front of the lantern is fitted with runners to carry colour mediums or lens attachment to produce small, clearly defined spots. These attachments are provided with masks of various sizes which are focussed by an additional lens.

Spotlights are made in various sizes to take projector lamps from 100 watts to 2,000 watts. Two forms of projector lamp are obtainable, the tubular, Class AI, and the round bulb, class B. The former is fitted with a filament that is optically more efficient while the latter is more robust and has a longer life. The type of work the spotlight is to be put to decides which should be used.

More elaborate forms of spotlight exist, notably the "Stelmar" and the "Strand Double Focus," these being designed to make the utmost use of the light from the lamp. These spotlights may be fitted with the 30-volt 30-ampère lamp with greatly improved results.

Where more powerful illumination is required, particularly for following artistes on the stage over long throws, resort is made to the arc lamp. The principle is the same as with the gas-filled lamp; the lantern, however, is much larger and better ventilated. Arc spotlights vary from 15 ampères to about 150 ampères, the latter being used for long front-of-house throws, and are mounted on heavy cast bases and fitted with various shutters, iris, barn door, etc., while the colours are changed by means of levers mounted at the back of the lantern. *See* Projector; Stage Lighting.

SPOT WELDING. One of three methods of applying resistance welding to two pieces of metal (usually when they overlap) by passing high currents through the two pieces at regular intervals along desired joint length. The joint produced is analogous to a riveted joint and can be applied under similar circumstances. *See* Welding.

SPREAD FACTOR. Also known as Distribution Factor or Breadth Factor. The voltages induced in the separate coils of a distributed winding are not in exact time phase, and their resultant is, therefore, less than would be given by a concentrated winding with the same number of conductors—*i.e.* a winding where the conductors of a phase are contained in one slot per pole.

The ratio of the voltages produced by distributed and concentrated windings having the same number of conductors is called the Spread Factor.

$$\text{Spread factor} = \frac{\text{E.M.F. produced by distributed winding}}{\text{E.M.F. produced by concentrated winding}}$$

It may be found for any form of winding by calculating the voltage induced in each coil (full pitch coils being assumed) accommodated in a single pair of slots, and then adding vectorially the voltages produced in all pairs of slots over which the phase is distributed. The ratio of this voltage to the voltage which would be produced, if all the conductors were concentrated in a single slot per pole, is the spread factor.

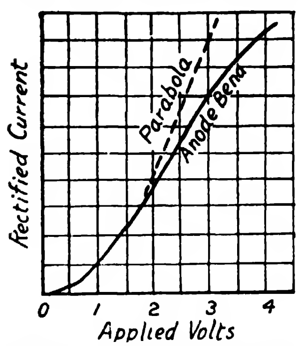
SPRING SWITCH. *See* Switch.

SPURIOUS RESISTANCE. The increase in the apparent or effective resistance of a conductor due to losses external to the circuit. For instance, when a conductor is associated with an iron circuit (*e.g.* an

iron-cored choke coil), and connected to an A.C. supply, it is found, in general, that a greater expenditure of energy is required to overcome the opposition to the passage of current than would be necessary to overcome the true or ohmic resistance of the conductor. This is due to the fact that energy is dissipated in the magnetic portion of the circuit, and these losses have to be made good by the electrical portion of the circuit. Because from the point of view of energy consumption these have the same effect as an added resistance in the electrical circuit, it is often convenient to consider them as such. The hysteresis losses in dielectrics have a similar effect on associated electrical circuits at the higher frequencies.

The increase in resistance caused by tne unequal distribution of current within the conductor because of voltages impressed or induced within it is not to be regarded as due to a spurious resistance. *See* Equivalent Resistance.

SQUARE LAW RECTIFICATION. The type of rectification given by a device in which the current passed, or change of current, is proportional to the square of the applied voltage. The rectifier characteristic is thus a parabola as shown in the graph. In practice a triode used as an anode bend detector gives approximately square law rectification for moderately low input voltages when the grid is negatively biassed just sufficiently to give zero anode current with no signal. The curve showing the change of anode current plotted against change of grid volts from the initial bias value is almost parabolic over the lower portion, as shown by the full line curve of the diagram.



SQUARE LAW RECTIFICATION
The dotted parabola represents a perfect square law. Anode bend curve approximates to this at the lower end.

Although square law rectification is not to be recommended for reception of radio telephony, as it introduces distortion, its use is an advantage in certain classes of radio work relating to measurements, an example being the rectification of beats produced by two H.F. waves, to obtain a beat frequency free from harmonics. *See* Heterodyne ; Rectification.

THE SQUIRREL-CAGE MOTOR: CONSTRUCTION AND STARTING METHODS

By Philip Kemp, M.Sc.(Tech.), M.I.E.E., A.I.Mech.E.

The simplest and most robust type of motor, used for all purposes and made in sizes small and large, is here described. As an induction motor the principles of its action are considered under the main heading for its class, Induction Motors. See also Faults; Motors; Slip-Ring Motor; and for the basic theory Electro-Magnetic Machines.

An induction motor having a permanently short-circuited rotor of a particular type. The rotor winding consisting of coils arranged in three phases, as in the case of the slip-ring type rotor, is now replaced by a much simpler arrangement. A squirrel-cage winding, or, as it is sometimes called, a cage winding, is scarcely a winding at all in the ordinary sense of the word. It consists of a number of straight bars, placed one in each rotor slot, these bars being all joined at each end by a ring of heavy cross-section, encircling the whole of the rotor or armature. These two end rings serve to complete the rotor circuit, and it is thus seen that the rotor circuit is permanently closed and always short-circuited on itself.

The stator of a motor of this type consists of a ring of stampings with slots cut along the inner periphery, these slots receiving the stator windings, which are three in number, in the common case of a three-phase motor.

The Rotor or Cage. The squirrel-cage winding itself is made of bars of relatively heavy cross-section, as also are the end rings, since it is desirable from the point of view of electrical performance that the

Fig. 2

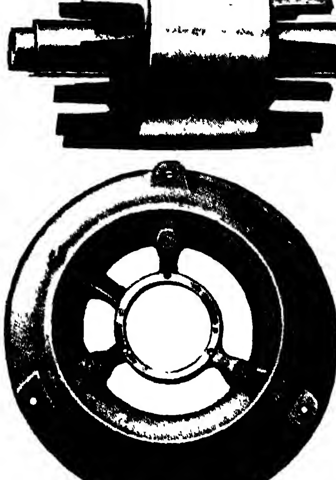


Fig. 1

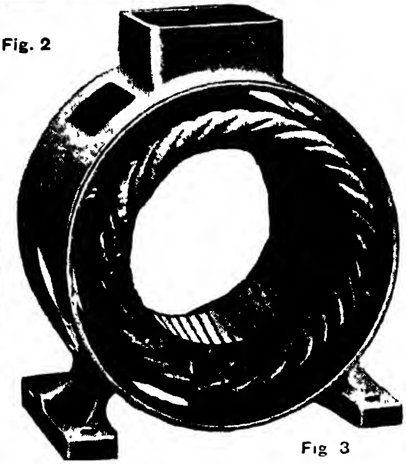


Fig 3

SQUIRREL-CAGE MOTOR. Fig. 1. End cover. Fig 2. Cast aluminium rotor. Fig. 3 Stator of protected type Witton squirrel-cage motor.
General Electric Co., Ltd., of England.

only about 2 or 3 mms. One bar is placed in each slot, lightly insulated with a slot lining. The end rings are usually not insulated at all, beyond a covering of varnish, since they stand in mid-air, and are stiff enough to need no support.

In the case of induction motors with wound rotors, it is usual to have the slot sides made parallel to each other, since as much slot width is required at the bottom of the slot as at the top in order to accommodate the winding which is probably of the two-layer type. This does not apply in the case of squirrel-cage rotors, where there is only one conductor per slot, since the cross-section of this conductor can be made to fit the slot. In such cases the teeth are made of uniform width all the way down, so as to avoid unnecessarily increasing the magnetic flux density near the tooth roots, this often being a limiting factor in designing a wound rotor The slots now narrow to the bottom, and the bars are shaped accordingly.

resistance of the winding should be as low as possible. The bars also should be bolted or riveted to the end rings, and not soldered, since it is at these points that high resistance may be expected, this giving rise to local overheating, just at the very points where it is undesirable.

The number of bars in the squirrel cage is always chosen as a prime number, as in such cases " cogging " or " tooth-locking " is avoided. If the number of teeth on the rotor equalled the number on the stator, there would be one position where all the rotor teeth are opposite to stator teeth, and the reluctance of the magnetic circuit in this position would be a minimum. In another position, teeth on the rotor would come opposite to slots on the stator, and in this position the reluctance would be a maximum. As the rotor moved round the flux would pulsate appreciably, varying between a maximum and a minimum value. This would give rise to irregularities in the torque set up, thus militating against smooth running. Even when the numbers of slots on stator and rotor have a common factor, this effect is present to some extent, and therefore a prime number is chosen for the number of rotor bars.

The rotor slots are made of the semi-closed type, the slot opening usually being

In one design for small motors the squirrel cage is of aluminium, the bar and end rings being cast in one piece after the rotor core is built This is made possible by the low melting point of aluminium.

Methods of Starting. Double squirrel-cage rotors have also been developed to meet the need for a squirrel-cage motor having a good starting torque. The great disadvantage of the squirrel-cage motor is that it cannot develop such a large starting torque as the corresponding motor of the slip-ring type, since added rotor resistance is necessary for this purpose. When two squirrel cages are provided, one is made with a low resistance to give the necessary torque when running, whilst the other is designed to have a high resistance to give the desired starting torque. The second cage winding is placed in slots underneath the upper slots, both slots having a narrow opening.

The stator windings are connected in star when the motor is designed for starting with an auto-transformer (*q.v.*), in which case the supply mains are connected to the three outer ends of the auto-transformer windings, while the stator windings of the motor are connected to the intermediate tappings. An alternative method of connecting the auto-transformer is to make use of the V connexions or open delta. In this arrangement only two windings are required on the auto-transformer itself, one end of each being linked to form a common point. This junction forms the connexion for one of the supply leads, the other two supply leads going to the two free ends of the two auto-transformer windings. Intermediate tappings are taken from these two windings, these two and a third lead coming from the common junction point forming the three motor connexions. This method has the advantage over that first described in that it is a cheaper type of construction, since there are only two coils to be provided on the auto-transformer instead of three.

Star-Delta Starting. An alternative method of starting squirrel-cage induction motors, one which has come very largely to the front in recent years, is the so-called "star-delta" method. The general idea is that the stator windings of the motor are connected in star during the starting period, and in delta when the full running speed has been attained, this change-over being effected by means of a specially constructed switch. The principal object of this is to reduce the otherwise excessive current that the motor would take at starting, were it to be connected directly to the line. The same is, of course, the case also with the two auto-transformer arrangements already described.

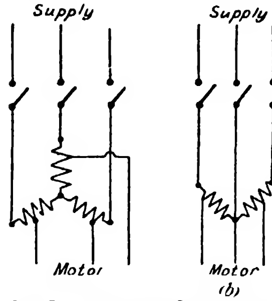
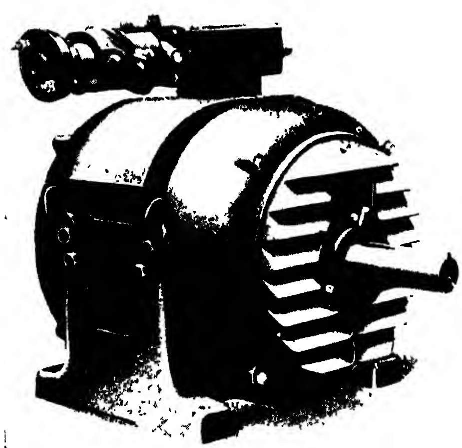


Fig 5 Auto-transformer connexions for squirrel-cage motor: (*a*) star, (*b*) V connexions

When three windings are connected in delta on a three-phase system, the full line voltage of supply acts across each of the three windings, and moreover the line current is equal to $\sqrt{3}=1{\cdot}732$ times the current in each of the three legs of the delta. With the same three windings connected in star, however, each winding receives only a reduced voltage. This is now equal to $\frac{1}{\sqrt{3}}=0{\cdot}577$ times the line voltage, and, furthermore, the line current is now only the current taken by one of the three windings, so that the line current is only one-third of what it would be if the motor were switched directly on to the line.

To see how this works out in practice, consider a motor in which each winding takes 45 ampères momentarily when connected directly across the supply. When the motor is first switched into circuit, the stator windings are connected in star, and so each winding receives only 57·7 per cent. of the full line voltage. It will take, therefore, only $0{\cdot}577 \times 45 = 26$ ampères when first connected, this being also the full current drawn from the supply, since the motor windings are now connected in star. If the motor had been switched directly on to the mains, each winding would have taken 45 ampères, and so the total current drawn from the supply would have been $1{\cdot}732 \times 45 = 78$ ampères, which is just three times as great as when connected in star. The steady full load current of this motor would be about 15 ampères, so that it is seen that the 78 ampères would certainly blow its fuses, or trip its circuit breaker, if this



SQUIRREL-CAGE MOTOR. Fig. 4. A 25 h.p., 970 r.p.m., 50 cycle, squirrel-cage motor with drip-proof cover.

British Thomson-Houston Co., Ltd.

were set to give efficient protection, whilst the motor could be arranged to stand 26 ampères momentarily without damage.

The above arrangement might be compared with that obtained by the use of an auto-transformer, the motor being fed from a 60 per cent. tapping, a reasonable figure. The stator windings of the motor will now be connected in star, so that, taking a motor of the same output as in the previous case, the line current would be 78 ampères when first switched into circuit. When fed at 60 per cent. volts, this current is reduced to $0 \cdot 6 \times 78 = 46 \cdot 8$ ampères, on the secondary side of the auto-transformer, the current on the primary side being $0 \cdot 6 \times 46 \cdot 8 = 28$ ampères approximately. This compares very closely with the 26 ampères taken when operated on the star-delta system. As the latter arrangement is cheaper, the reason for its popularity is obvious.

Squirrel-cage rotors are exceedingly robust in their construction, and are subject to practically no faults other than those of a mechanical nature (*see* Fault Finding).

SQUIRREL - CAGE WINDING. An induction motor in which the rotor conductors are short-circuited on themselves is said to have a squirrel-cage winding. The conductors are usually composed of heavy copper bars having their ends permanently short-circuited by copper rings. The great advantage of such types of winding lies in the inherently low resistance and reactance of the rotor. When such a motor is connected to supply a starting current will flow, four to seven times the full load current (increasing with the size of machine), and the torque exerted will be perhaps twice full load torque. Reduction in starting current results in considerable decrease in torque and squirrel-cage motors are therefore only suitable for starting on light loads.

For duties where speed regulation is unnecessary and the starting torque is light the squirrel-cage winding is universally adopted on account of its cheapness, robustness, high efficiency and high overload capacity and the absence of external connexions to the rotor. *See* Induction Motor ; Squirrel-Cage Motor.

STAGE LIGHTING IN THE MODERN THEATRE

By Frederick P. Bentham

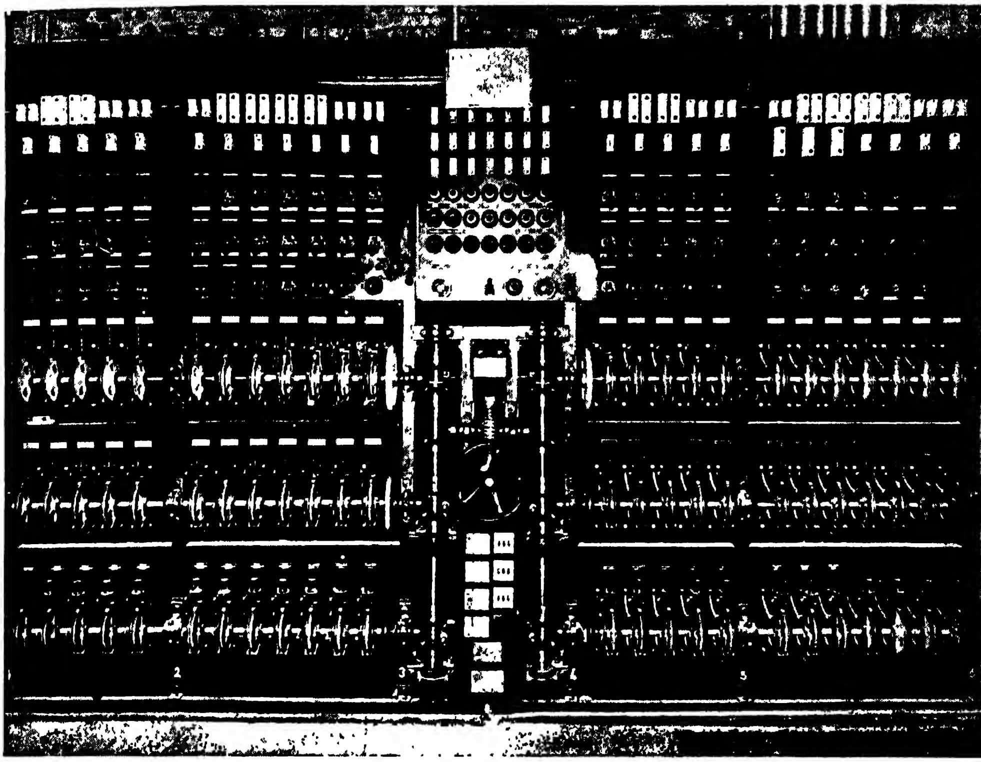
This important branch of the electrical engineer's work, while being of specialist nature and therefore discussed here by a specialist, is in part a development in a particular direction of the lighting work considered under the headings Floodlighting ; Illumination ; Lighting, etc., to which reference should be made. The stage switchboard in its most modern forms is the subject of a special section of the present article. See also Cinema Plant ; Cyclorama; Dimmer; Projector ; Spotlight.

This subject is definitely a specialist one and combines the technical with the artistic. The apparatus in a large stage lighting installation falls into four groups : (1) Acting area lighting ; (2) the back-cloth lighting ; (3) front-of-house lighting ; (4) portable lighting.

The simplest form of stage lighting installation consists of rows of lamps of different colours. These are suspended overhead and are mounted along the front edge of the stage, the former being known as battens (*q.v.*) or borderlights, and the latter as the footlight or float (*q.v.*). The latest and most efficient type of battens consist of a sheet steel housing divided into compartments seven inches wide, containing a silvered glass reflector and a 100 or 150 watt lamp mounted in an E.S. holder. The front of the compartment is fitted with a runner for colour frame and gelatine medium. The compartments are wired alternately on three or four colour circuits, these circuits being further sub-fused according to the length of the batten, in order to comply with the I.E.E. regulations. Each colour circuit is controlled by a switch, a dimmer and a pair of fuses on the stage switchboard. The battens are suspended from the stage by counterweight gear.

The footlight is constructed in a similar manner to the battens. This apparatus may be considered the foundation of any stage lighting equipment.

In some cases the battens, footlight and control board are the only permanent apparatus in the theatre, the remainder



STAGE LIGHTING. Fig. 1. Stage switchboard and dimmer bank at Regal Cinema, Edmonton.
Strand Electric Co, Ltd.

being hired for the particular production. This is due to the fact that in most theatres all over the country the management of the theatre is not directly responsible for putting on the productions at their theatre. The theatre is rented by an independent production company. The requirements of the various companies may vary so much that a comprehensive equipment would be far too expensive to make the theatre an economic proposition. Provision is, therefore, made for the connexion of temporary switchboards and apparatus. This takes the form of a "special effects" board fitted with quick connexion terminals. In provincial tour theatres a different set of temporary apparatus (toured by the various companies) is connected up each week.

Use of Spotlights. Apparatus which might advantageously be added to the permanent equipment would be perch spots (spotlights or boomerangs), four or more 1,000-watt spots mounted vertically on a barrel on each side of the proscenium arch, focussed on any particular part of

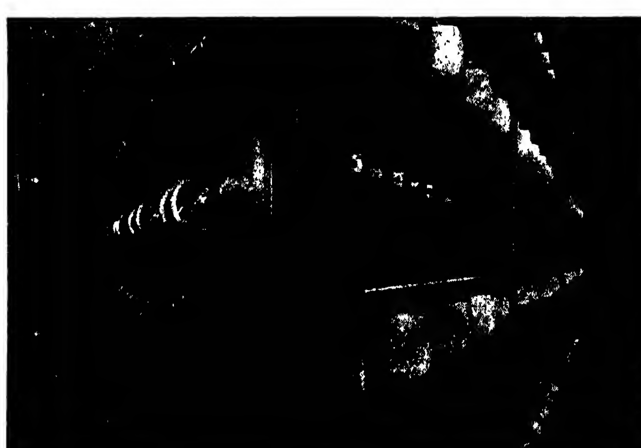
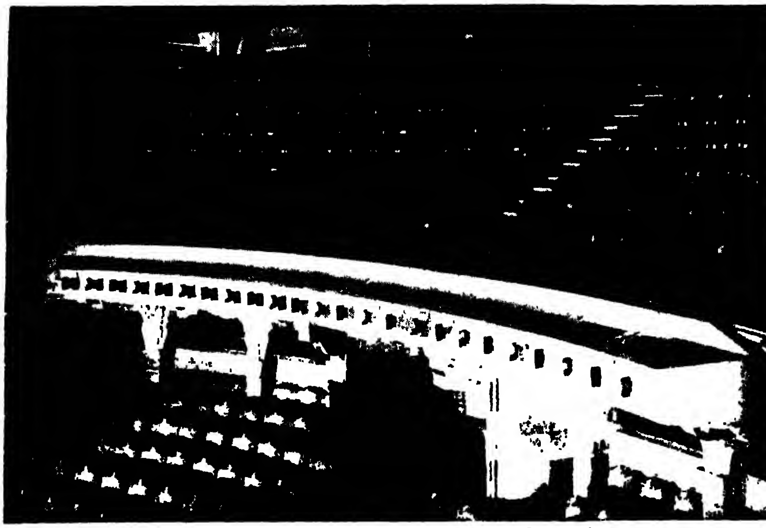


Fig. 2. Side view of dimmer control panel at Royal Opera House, Covent Garden.
Strand Electric Co., Ltd.



STAGE LIGHTING. Fig. 3. The well-lit auditorium of the London Hippodrome, showing battery of balcony spotlights.
Strand Electric Co., Ltd.

with magnetic apparatus by which the colours may be changed from the stage board.

Repertory Theatres. In repertory theatres a different system must be used. For the lighting equipment, like the cast themselves, must cover a range of productions without additions. As expense for scenery must be kept down a stylized setting is more usual. Here it is that the cyclorama (*see* Cyclorama) may be used with the greatest effect. With the cyclorama the lighting must be localized to an extent not possible with the straight type of installation already described. When lighting this type of stage it is as well to treat the cyclorama and acting area as two separate entities, each entirely independent as regards lighting. On the ideal stage it should be possible to flood the cyclorama in one colour and the acting area in another, without overlapping. A large repertory theatre such as the Shake-

the stage. These used for creating light and shade.

When the artistes have to be picked out and followed, as in musical comedy or variety, arc spots from the perches or front-of-house, or both are used. The perch arcs would work on 20–30 ampères, the front-of-house 40–80 ampères, or more according to the length of throw. As No. 1 batten hangs behind the proscenium arch, when artistes are working down stage, that is, immediately below or in front of No. 1 batten, their faces depend for their illumination entirely on the footlight, causing very unnatural shadows. To obviate these shadows light is projected from spots in the front-of-house. These are of 1,000 or 2,000-watt size and generally mounted in housings on the circle fronts. Large theatres will be equipped with sixteen or more such lanterns mounted both on the dress circle and upper circle fronts. The function of these lanterns is to provide a light auxiliary to, or in substitute for, the footlight. As mentioned later, they are invaluable when a cyclorama (*q.v.*) is installed. These lanterns are frequently fitted

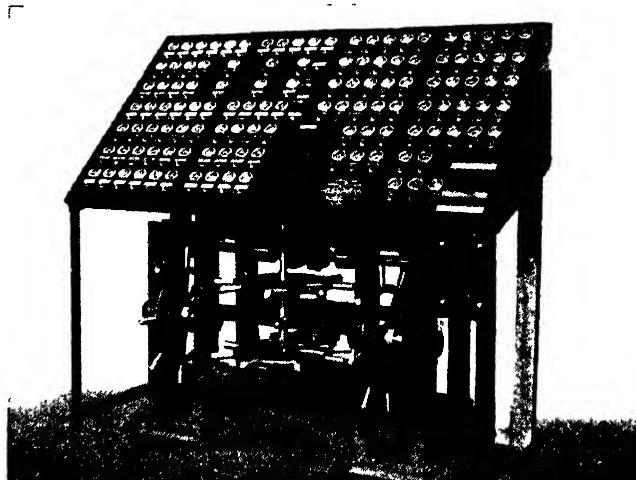


Fig. 4. Remote dimmer bank control at the Royal Opera House, Covent Garden.
Strand Electric Co., Ltd.

speare Memorial Theatre is equipped with a set of battens and footlights as well as the special apparatus for the cyclorama.

On the average repertory theatre stage one batten consisting of spots and floods for the acting area and one batten of floods for the cyclorama will be sufficient. This will be supplemented by spots from the auditorium so arranged that while lighting the actor's face they do not throw his shadow on the background. These spots will deputize for the footlight and should never be less than 1,000 watts each. For No. 1 batten, 500-watt spots and 500-watt floods will be sufficient. Each unit will be controlled from a dimmer. The cyclorama for a small stage could be satisfactorily illuminated by twelve 500-watt floods from above, six to the blue, three to the red and green. The floods will be mounted on a barrel and controlled from three dimmers. A much greater range of effect can be obtained when a ground row is used as well; it is constructed on similar lines to the footlight.

Large Installations. In the case of very large theatres pursuing a definite production policy of their own, extensive installations to cover, as far as possible, all requirements are used. The most notable of these installations as far as England is concerned is Covent Garden Opera House. The following is a brief description of the installation at the Opera House, an installation which is the largest in the British Empire. From this, it will be possible to see the general principles which govern the lighting of both cyclorama and "straight" stages.

The majority of the lighting apparatus is mounted over the proscenium arch and includes the main bank of 1,000-watt floods in three colours for lighting the cyclorama; No. 1 batten, which consists of 1,000-watt spots and 500-watt floods, and a bridge which carries a number of 2,000-watt spots, 1,000-watt focus floods, optical effects projectors, and their operators. On either side of the arch there are platforms one above the other (known as perches) which carry special lanterns employing a very elaborate optical system, in conjunction with a 1,000-watt lamp. These lanterns have replaced arcs for spotting purposes in this theatre. Spaced at regular intervals to the back of the stage follow Nos. 2–5 battens. These are of the magazine type previously described and are used with the border settings. In between the sections of these battens are a number of special acting area lanterns designed to illuminate the stage when the cyclorama is in use. These lanterns are of the narrow angle flood type. Midway between the cyclorama and the proscenium arch is a further bank of 1,000-watt floods designed to give additional illumination on the cyclorama at the point where it is furthermost from the main bank. The bottom lighting is achieved by 500-watt wide angle floods mounted on trucks connected together making them readily removable for scene changing.

In addition, the standard magazine footlight is installed, and a large number of dip plugs are available for portable apparatus, while three special spotting lanterns, using 30-volt, 30-ampère lamps, are situated in the dome front of house. These lanterns are fitted with electric colour change controlled from the stage board. The whole of the installation is controlled by dimmers (of which there are 150) operated magnetically from a small control panel on the P. perch.

It can be seen that the above type of installation covers both the requirements of the straight stage and the cyclorama stage. The dip plugs are numerous and fitted with various dimmers to feed the wing floods, hanging lengths and the rest of the miscellaneous lighting equipment required to illuminate the backings behind doors, wings and other special lighting required to overcome the peculiarities of each scene. Arc plugs are fitted for any optical effect lanterns that may be used from stage level, and lastly independent plugs are provided for fires, lighting fittings, and other electrical properties. These plugs are installed in various strategic points about the stage. The whole of the main stage lighting is balanced over three phases with a separate D.C. supply for the arcs.

Variety and Cinema Stages. There are left two types of stages whose requirements are rather different from what has already been described. Delicate or realist effects have very little place in the variety theatre. The object here is to focus attention generally, to the exclusion of all else,

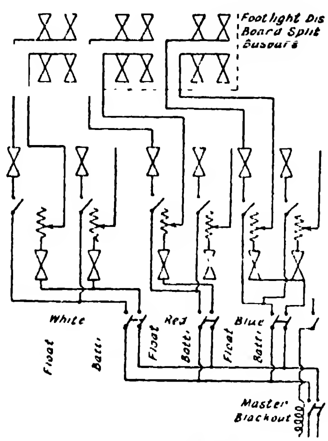
on the performers, sometimes one artiste only. Therefore, the modern variety theatre installation provides arc spots for following from the perches, and also two or three or even more from the auditorium. In this type of installation these spots form the dominant apparatus.

In the modern cinema, stage lighting is regarded from a different angle. In the legitimate theatre, the lighting and setting is an accompaniment to the actor. In the cinema generally the lighting of the setting is regarded as an attraction equal to the turn presented. Very often the lighting is used to provide the visual side of an organ interlude. Then, again, very little, if any, scenery is used, and the whole effect must be obtained by means of coloured light on a limited number of draperies. To aid this the usual battens and footlights are installed wired for four-colour circuits (red, blue, green and white) and several triple 1,000-watt floods mounted on light movable frames. These floods are fitted with the three primary colours, and are used from the wings. The object of these floods is to put the high lights on the folds of draperies, etc., thereby making them alive with light. When artistes are introduced they are spotted from the projection-room. Frequently a super-cinema will put on a half an hour or so of legitimate variety. In the Regal Cinema, Edmonton, six front-of-house arc spots are installed. As there are two Brenograph effect machines, each giving, if need be, two spots, a total of ten arc spots can be brought to bear on the stage. Incidentally, this stage is fully equipped with cyclorama lighting, battens, and footlights on a scale which dwarfs most legitimate theatres. This, although rather exceptional, applies to several of the big super-cinemas.

The Stage Switchboard

This term is used to cover the apparatus from which a stage lighting installation is controlled and includes the dimmers. This is the most important part of the installation, and the type of board installed should not only be adequate for its present installation, but should be easily adaptable for extension.

Direct Operated Boards. The commonest type of switchboard is the direct operated, arranged in colour groups. A board of this type will almost invariably control the standard three- or four-colour stage installations consisting of battens, footlight and dip plugs. All the circuit switches and dimmers for each colour are grouped together. The circuit switches are supplied through a colour master switch, while the dimmer control handles for each colour are mounted on one shaft to which they can be locked for collective operation, by means of a quick-motion wheel or a slow-motion geared drive at the end of the shaft. Such a board will be dead front, the switches and dimmers being behind the control panel, operated by handles and rods.



STAGE LIGHTING. Fig. 5. Three-colour control for battens and footlights.

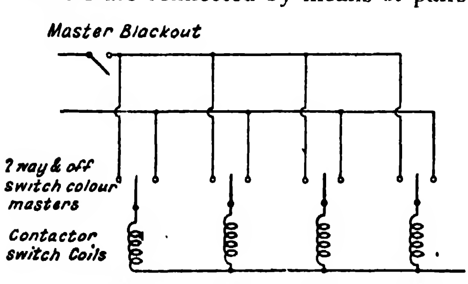
On a small board the colour master switches will be back of board type, but on larger boards owing to noise these must be contactor switches out of hearing of the stage. When contactor switches are provided to each colour they are usually controlled from two-way and off tumbler switches on the switchboard. One side of all the two-way and off switches is fed through an extra one-way tumbler switch, and the other side remains live. This enables the operator to select his colour masters for blackouts.

The dimmers and switches for certain dip plugs, spotlights, etc., are grouped together to form a separate bank generally painted black. Each individual circuit switch for this bank is of two-way and off type, one side being connected to a busbar fed from the independents master, the other to a live bus-bar. This enables the operator, by pre-selection of the switches, to black out the stage, leaving certain circuits on. This is frequently necessary as, for instance, where a character will

switch off a chandelier in a drawing-room set, leaving, however, a fire and a table standard alight. This effect requires that the chandelier plus the majority, but obviously not all of the stage lighting, must be blacked out. The switch that the actor works in view of the audience gives a light signal to the electrician at the switchboard, who, by previously switching certain circuits over to the live bus-bar, carries out this effect instantaneously from one switch, *i.e.* the master blackout.

The handles of the dimmers on smaller stage boards are locked together for master operation by screwing them down on to the shaft. On larger boards friction clutches operated by a quarter turn of the handle and fitted with some means temporarily to stop them gripping at either end of the travel, are fitted as standard. These are known as self-release handles and enable dimmers to be brought up in succession without manually releasing the preceding handles from the shaft, thereby simplifying operation. They must regrip the shaft when it is reversed in order that should the producer require a repeat of a particular cue at rehearsal there shall be no delay. Frequently a pilot lamp is installed over each dimmer-handle, giving an indication of the intensity of light in that circuit.

Remote Control. Where the number of dimmers and switches is such that a direct control board would be excessively long, resort is made to remote control. The circuit switches are of contactor type, while the drive of the dimmers is effected in two ways. Either each dimmer is provided with a reversible motor and reduction gear, or a driving shaft is constantly revolved in one direction by a motor and reduction gear, while the dimmers are connected by means of pairs



STAGE LIGHTING. Fig. 6. Schematic diagram of wiring for control of contact or colour masters.

of magnetic clutches to go up or down at the will of the control panel operator.

These magnetic clutches are used in connexion with the Covent Garden Opera House switchboard. In this case, however, a manual drive is used, the various dimmers being selected to travel up or down by means of two-way and off switches. The driving shaft is then put into operation by means of a quick-motion wheel or a slow-motion wheel. In this control there are two driving shafts, one for the colours and one for the independents. These shafts can be locked together for master operation. Indication of the position of the dimmers is given by electric indicator dials. These dials are so arranged that even when the current is switched off the dimmers by means of the circuit switches or the master blackouts, the dials continue to indicate the position of the dimmer. A more elaborate control is the pre-set. The " Major " multi-scene pre-set switchboard enjoys a great vogue in America.

Pre-Set Boards. The pre-set board enables the operator to pre-select the lighting for several scenes by means of pilot switches. This lighting is brought into operation by means of one switch known as the scene master switch. Any type of pre-set switchboard which works circuit switches only is quite useless, as is also a pre-set board which operates the dimmers up or down.

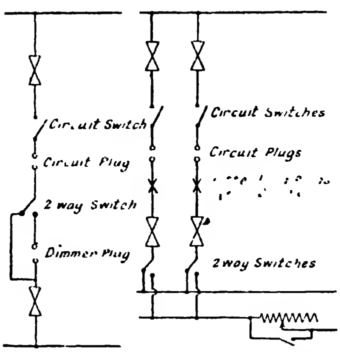
Modern production practice demands that coloured light be mixed, which means that each scene requires the dimmers to be moved to different intermediate positions. In fact, the theatre electrician makes a practice of putting all his circuit switches on and working on the dimmers for his changes. Probably the most complete pre-set board at present available is the " Strand." In this board not only may the positions of the dimmers be pre-selected for a large number of scenes, but the speed with which each individual dimmer moves to its new position can also be pre-set. The whole control is remote, being connected by a multicore telephone cable to the main bank.

Hydraulic Control. There is yet another type of control which may be deemed to come under the pre-set category; this is the Strand Salaman hydraulic control.

In this type, the dimmers are operated by rams under oil pressure, the speed of dimmer travel being determined by valves. The dimmers can be set to travel at different speeds, the master valve is opened and the change takes place. This control gives a wide range of speeds, some being so slow that the complete dimmer travel would take three hours. A board of this type has been installed for some years at the Royal College of Music, but its value in all but exceptional cases may be doubted.

It is to be borne in mind, however, that there is considerable difference of opinion as to the value of pre-set boards. The number of changes required during a production is becoming so great that a pre-set to set up the lighting with entire automatic or semi-automatic control would not be practical. It is generally realized that a competent operator must stand by at each performance. Therefore, a compact portable control in full view of the stage is required which will enable the operator to carry out every possible light movement, and also to combine such movements so that they may be performed simultaneously.

Tracker Wire Control. In various theatres over the world, switchboards of widely differing designs are to be found, each one representing an attempt to solve the problem. In Germany, the larger theatre installations employ tracker wires very extensively. Not only are the dimmers controlled from a remote point by means of long and complicated tracker wire systems, but the colour screens in front of the spotlights, acting area and other lanterns. Dissolving and masking shutters are also controlled by this means. All these wires terminate in the control, which is sometimes situated under the footlights with an aperture which enables most of the stage to be seen, but more generally from a perch on the side of the stage. While this may be described as centralized control, all tracker wires certainly terminating at the one point, the question of the control of the controls arises. This will be discussed more fully later on.



STAGE LIGHTING. Fig. 7 (left) Circuit for flexible board. Fig. 8 (right), double flexible board circuit.

Tracker wire systems have the great fault that they are very liable to give trouble which only constant supervision can prevent. This is generally due to the wires being too tight or too loose, the former causing them to squeak, the latter to override the guide pulleys, etc.

New Types of Dimmer. The arrival of new types of dimmer itself, notably that employing the Thyraytron (*q.v.*) tube or the variable choke, has led to the main consideration in the matter of control being overlooked. In these dimmers the absorption of electrical energy by introducing wire resistance and turning it into heat, is replaced by a voltage control. This form of dimmer has the advantage that it is economically sound, takes up a smaller space and furthermore, since such a dimmer operates by reducing the voltage, the load on the particular dimmer can vary a great deal without altering the dim. In the case of the Thyraytron tube the change of voltage is brought about by means of a small rheostat, and in the simple reactance choke, a small variable resistance which occupies about a tenth of the space of a standard dimmer plate.

The Light Console. However, as the number of dimmers on a large installation may be anything over sixty, the question arises how to control sixty knobs, however small. Arrangements must be made to group the dimmers, circuit switches, etc., instantaneously so that as many operations may be carried out by one pair of hands as possible. Such a control is the Strand Light Console, which is the latest and most complete form of switchboard design. Briefly, the board applies the modern forms of organ control to the needs of stage lighting. It is the most compact type of control yet designed, and will carry out any operation required: speed control, position control, switching control, instantaneously. It is connected to the main dimmer bank by means of a multicore organ cable and a detachable

plug. The console is small, being 4 ft. wide, 3 ft. 6 ins. high and 2 ft. 6 ins. deep, and will control any number of dimmers to cover all possible needs. The console can be plugged up in the stalls next to the producer, for rehearsals, and in the orchestra pit or wherever desired to give the operator a full view of the stage.

The console operates on wire-wound resistances, chokes, or shutters in front of the lighting units (as may be necessary if the new hot cathode tubes are used for cyclorama lighting) without any alteration in the form of control, as far as the operator is concerned.

Flexible Control. There is yet another type of switchboard, the flexible control. There are various (in point of fact, unlimited) types to be found A good many of these defeat their own ends by being so flexible that to master the boards requires concentration and a brain that are beyond the powers of man to supply. The most famous in this country is installed at the Royal College of Music, London. Here a highly ingenious switchboard has no complete circuits at all, the circuits being connected up to include whatever is required by means of plugs. It provides endless possibilities in theory, but if the electrician were absent no one could use it with any feeling of ease. This switchboard works in conjunction with the hydraulic dimmer bank previously described.

A simple but effective circuit for a flexible board is shown in Fig. 7. This provides a plug for the outgoing pair to the lamps. Some of these plugs would not be situated on the board itself, but in convenient positions on the stage. Also, a plug for a dimmer to be inserted, which may be cut in or out by a two-way switch. An improvement can be effected by fitting Rottenberg plugs; these plugs enable the dimmer to be plugged in without a flicker. A further improvement which gives connexion as required on to a master dimmer is shown in Fig. 8.

With a switchboard on these or similar principles, the lighting for a stage can be catered for by a switchboard of a limited number of ways with a few dimmers of various wattages. Only those circuits required being connected up for a particular scene and dimmers of the wattage needed can be inserted where desired. This effects a great saving in cost of installation. The board takes up less room than one with the full complement of dimmers. This type of switchboard is extremely useful in amateur or little theatres where expense and space are important considerations.

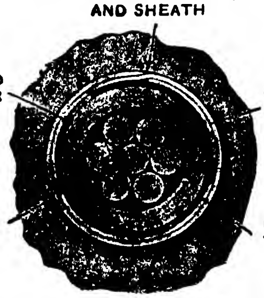
STALLOY. Name given to a particular type of steel, the predominant constituents of which are iron and silicon. Other constituents include sulphur, manganese and carbon. A greater proportion of silicon has the effect of raising the specific resistance, but also decreases the losses due to hysteresis. Stalloy is used in wireless work, in diaphragms of telephones, and also as laminae in the cores of some transformers. By its use in the latter case, the losses in a core of given size working at a given flux density may be only a fraction of those which would occur with ordinary iron. *See* Iron Loss; Lohys, *etc.*

STAMPINGS: ARMATURE AND TRANSFORMER. The armature core is built up of a number of thin sheet steel discs keyed on to the armature shaft and clamped solidly together. In large machines, over 3 ft. in diameter, the discs

STAGE LIGHTING. Fig. 9. Complete lighting control console.
Courtesy of Strand Electric Co., Ltd.

are segmented and arranged so as to break joint in alternate layers. The thickness of these stampings varies from 14–25 mils., and they are lightly insulated with varnish, paper, or merely a film of oxide, so as to lessen eddy currents in the mass of the core. The net section of iron in the core is therefore only about 90 per cent. of the gross section. The discs are slotted to receive the armature conductors prior to assembly, and no machine work other than light filing should be done after assembly (*see* Laminations).

Similarly, to reduce the eddy current and hysteresis losses in transformers, the cores are built of thin sheets of iron alloy such as Lohys or Stalloy (*q.v.*). For 50-cycle cores, however, high resistance steel is commonly employed, the thickness of the stampings ranging from ·014–·02 in. With thinner plates the loss is decreased, but the space factor is lower and the cost of punching and assembly is increased. For insulation between the discs, paper 1–1·5 mils. thick is employed, though enamel or varnish is occasionally relied on.



STANNOS WIRING SYSTEM. The particular feature is the tinned copper outer sheath acting as armouring and also as return conductor.

High-silicon iron, being very hard, is liable to wear the dies and cause burrs. The stampings should therefore be punched so that the burrs are on the uninsulated side and burrs should be filed off to prevent short circuits between laminations. Clamping bolts and side plates should also be insulated from the core.

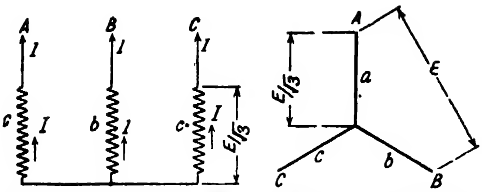
STANDARD CELL. Name given to a primary cell used for standard test work. Such a cell is designed to give a constant and reliable electro-motive force irrespective of all local conditions, and it is only affected by temperature. Such a cell is the Clark cell, and this is adopted by the Board of Trade as a standard in test work. The Weston cell is also a standard cell. *See* Battery ; Cadmium Cell.

STANNOS WIRING SYSTEM. The leading feature of this system is the use of tinned copper strip as an outer sheath. It is applied in a special manner over one, two, three or four cores each insulated with vulcanized indiarubber and layers of paper. The copper cover is a good and permanent armour, and in the case of concentric wiring acts as the return conductor. The conductors are damp- and vermin-proof and the system is exceedingly neat and unobtrusive when erected, and is much more durable than most of the metal sheathed methods of wiring. With this system there is no appreciable inductive loss with alternating currents.

Stannos wires are well suited for extensions to existing conduit systems in fine buildings where it is undesirable to disturb surfaces. The larger sizes are quite suitable for service cables, and in virgin soil can be successfully laid underground. Where the ground is made up the conductors are best taped, jute served and compounded. It is claimed that when Stannos cables are used as a concentric system they make up the least expensive system in general use.

On some jobs it is worth while to arrange Stannos wiring on the three-wire principle. The two inner wires are connected to the transformer secondary terminals and the sheath to a mid wire earthed tapping. The sheathing then serves as the third or neutral return and is earthed at various points vide I.E.E. rules. The lamps in such cases must suit half the secondary pressure. Stannos wires ordinarily range from 1/·044 to 7/·064. Suitable tinned copper continuity fixtures, boxes, etc., are available. *See* Wiring.

STAR CONNEXION. The star connexion of the windings of machines, transformers, voltage regulators, etc., is adopted in A.C. working for various reasons associated both with the design of the plant and its operation on the system. Compared with a delta-connected winding, the star connexion permits a more robust winding, as for the same



STAR CONNEXION. Fig. 1. Three phase systems have common terminal for star connexion. Voltage per phase is 58% of voltage between lines.

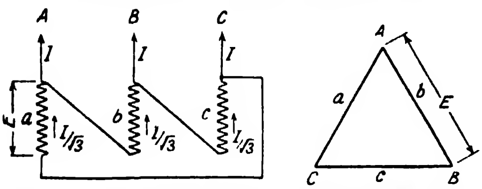


Fig. 2. For mesh or delta connexion as shown, current per phase is 58% of current per line.

current density the conductor section is 73 per cent. greater and total space taken up by interturn insulation is less. For a given line voltage the number of turns per phase winding is only 58 per cent. of those in a delta winding. If the star neutral is dead earthed no part of a star-connected winding can reach a potential above earth greater than the star voltage, and the average potential to earth of the winding is one half that amount while the minimum potential is zero.

On an unearthed delta-connected system the winding can be subjected to full line voltage above earth, under earth fault conditions; under normal balanced voltage conditions the maximum voltage to earth is 58 per cent. of the line voltage, the average is 43·5 per cent., and the minimum to earth is 29 per cent. of the line voltage.

The star and delta connexions are shown diagrammatically and vectorially in Figs. 1 and 2. These indicate the relative magnitudes of voltages and currents in the respective windings and in the lines connected to them. For the same line voltage and current the total power rating of the two connexions is the same, as shown by the following expressions:

Star connexion: $P=\frac{E}{\sqrt{3}}\times I\times 3=\sqrt{3}EI.$

Delta connexion: $P=E\times\frac{I}{\sqrt{3}}\times 3=\sqrt{3}EI.$

All apparatus having magnetic circuits which are rated at commercial induction densities contain higher harmonic quantities in the magnetic or electric circuits, and of these the third harmonic usually is the most important. In a three-wire star connexion, third harmonic voltages are produced in each winding, and as they are in phase with each other therein a third harmonic voltage appears from the neutral point to earth.

In the delta connexion, the third harmonic voltages are short-circuited by the delta so that third harmonic currents, which are in phase with each other in all three windings, flow around the closed delta but not in the line. These third harmonics serve to provide the necessary excitation required by the varying permeability of the magnetic circuit. If the relationship between B and H of the magnetic circuit was a direct proportionality (as in the case of an air circuit) no higher harmonics would be produced. By careful design, higher harmonics may be reduced to negligible proportions, however. In transformers, one winding is usually delta connected in order to minimize third (and odd multiple) harmonics. Even with a delta connexion of one winding, third harmonic currents may flow on the star-connected side if the neutral be earthed and the connected lines possess appreciable capacitance.

In the star connexion similar ends of the phase windings are connected to form the neutral point, *i.e.* the "starts" or the "finishes" of the phases.

In the delta connexion the "start" of one phase is connected to the "finish" of another phase, and so on.

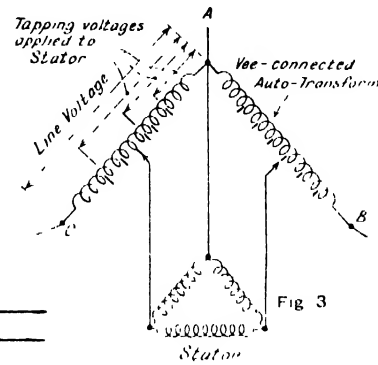
The star connexion has the great advantage that a neutral point is available for earthing and for a fourth wire for loading purposes. *See* Delta Connexion; Harmonic; Star Voltage; Transformer, *etc.*

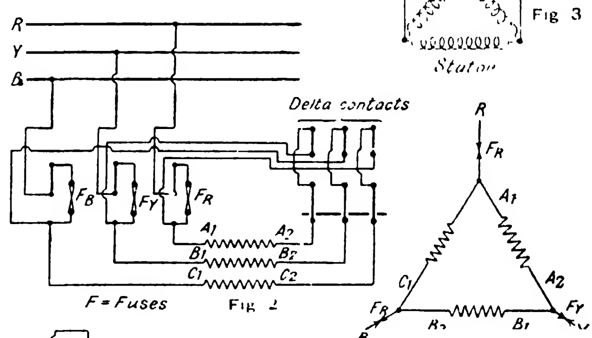
STAR-DELTA CONTROL. Star-delta control is used for starting-up three-phase squirrel-cage induction motors in those cases where it is not permissible to switch the motor direct on to the mains. The line of demarcation between the h.p. of motors which may be switched on direct or to which star-delta (or other) control must be applied, varies according to the size of the supply undertaking and of the feeder or distributor supplying the motor. A limiting size of motor for direct switching on is commonly given as 5 h.p., although some undertakings set it as low as 3 h.p., and others as high as 15 h.p.

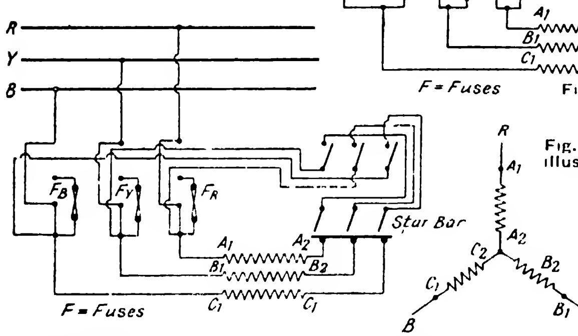
Pure star-delta control consists simply of a star-delta starting switch having two positions, in one of which the stator windings of the motor are connected to the line in star, while in the other position they are connected in delta. The first corresponds to the starting conditions and the second to the normal running conditions. Both ends of each stator phase windings must, of course, be brought out to separate terminals in order that this method of control can be adopted.

When a squirrel-cage motor is switched direct on to the line, a rush of current ensues before the machine starts up, and the magnitude of this current is simply the applied phase voltage divided by the motor phase impedance, which latter is practically constant. If, then, a certain line voltage be impressed across star-connected stator windings, the line current is proportional to $E/\sqrt{3}$ or 58 per cent. of the line voltage, while if the windings be delta connected the line current is proportional to the full line voltage, and is thus 73 per cent. greater than the line current taken by the star-connected windings.

Heavy current rushes in the lines produce momentary voltage drops which may have undesirable effects on lighting connected to the system, while in the extreme case, if numerous squirrel-cage motors were switched on direct simultaneously, voltage drops of such magnitudes might be produced as to cause synchronous machines to fall out of step. Fig. 1 shows the diagram of connexions for the starting position and Fig. 2 for the running position. In these diagrams it will be noticed the fuses are arranged so as to be in circuit during running conditions only, in order that they shall not be subjected to the effects of large starting currents. Star-delta switches can, if necessary, be made automatic and fitted with the usual overload and no-volt releases.



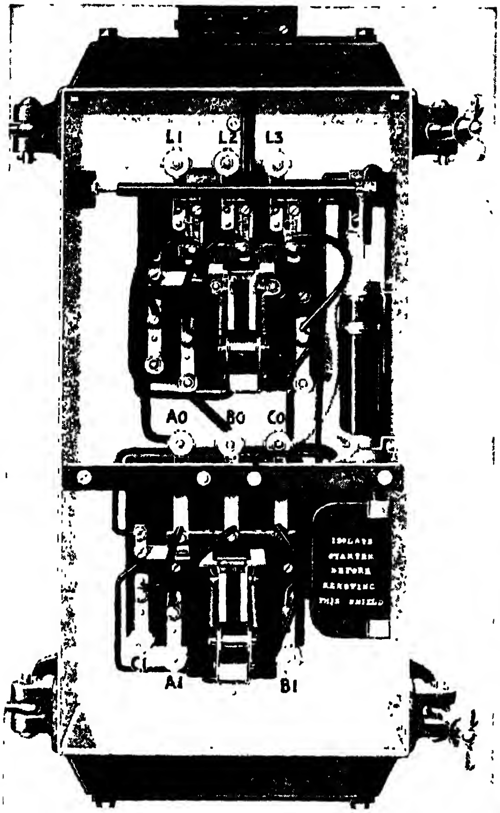




STAR-DELTA CONTROL Fig 1 Diagrammatic scheme connexions for starting position in a star-delta starter.

Fig. 2 Running position star-delta starter, illustrated in Fig 1 Fig 3 Auto-transformer starter connexion

In those cases where the initial application of the supply voltage to star-connected stator windings does not give sufficient starting torque, an alternative to the star-delta switch is the auto-transformer starter (*q.v.*). In this arrangement, which is illustrated by Fig. 3, the stator phase windings are permanently connected in their normal running manner and the motor terminals are connected to a vee-connected auto-transformer through a tap-changing switch. The auto-transformer is provided with a number of tappings, 3 or 4 in number, giving voltage steps ranging from about 40 per cent. to 80 per cent. of full line voltage. The motor is switched on to the line at the lowest tap voltage and change is then made from tapping to tapping to obtain the necessary



STAR-DELTA STARTER Fig. 1. "Auto-Memota" push-button operated starter fitted with automatic change-over from star to delta connexion.
Midland Electric Manufacturing Co., Ltd.

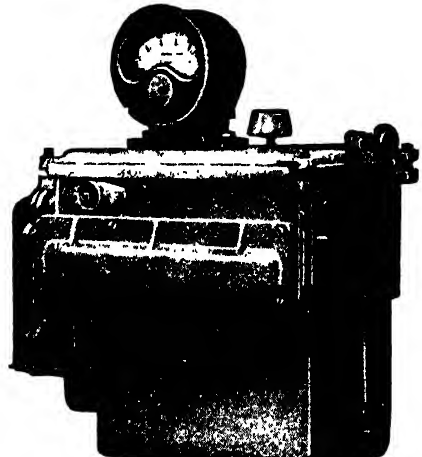


Fig. 2. Oil-immersed ironclad starter fitted with ammeter and cable sealing box.
J. G. Statter & Co., Ltd.

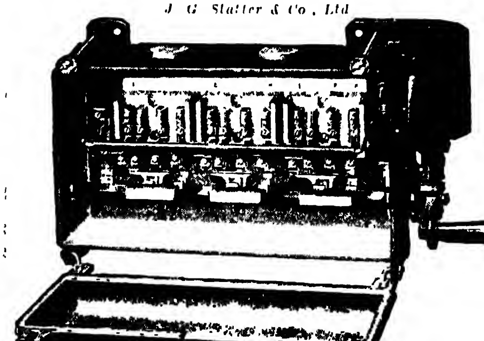


Fig. 3. "Memota" manually operated starter suitable for squirrel-cage and certain other types of induction motors up to 10 h.p.
Midland Electric Manufacturing Co., Ltd.

starting torque. The advantages of this method of starting will be realized when it is remembered the torque is proportional to the square of the applied voltage. Thus, if we call the starting torque at 40 per cent. of line voltage, unity, the following relative values ensue:

App'd voltg in % of line voltage .	40	50	60	70	80	90	100
Relative start'g torque .	1·0	1·56	2·25	3·06	4	5·06	6·25

With the star-delta starter the relative torque (on the above basis) at starting would be 2·08, *i.e.* only one-third of normal full-load torque; if, as with large machines, this is insufficient, the auto-transformer starter provides the solution.

STAR-DELTA STARTER OR SWITCH. Apparatus used for starting three-phase, squirrel-cage induction motors which are too large to switch direct on to the mains but not large enough to need higher than 58 per cent. of full line voltage to develop the necessary starting torque. The switches are generally of the low voltage, air-break type, enclosed in metal housings, and, apart from the arrangement of contacts necessary for the change from star to delta interconnexions of the motor stator windings, they are of standard construction.

They may be fitted with automatic overload and no-volt releases if desired, and also with fuses. *See* Induction Motor; Star-Delta Control; Starter (p. 1150).

STAR POINT. Star point of a system of any number of conductors is the common junction formed when the conductors are connected in star formation. The term usually is applied to A.C. three-phase and six-phase circuits, but is not necessarily confined thereto. Gener-

ally, it is the windings of machines, transformers, reactors, voltage regulators, etc., that are star connected, and if the individual phase windings are truly balanced in all respects, and not subjected to an external electrostatic or similar influence, the star point is at zero potential.

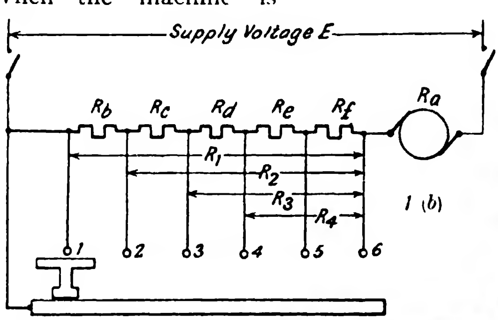
Potential differences which *might* be present at the star-connected ends if they were isolated from each other, are neutralized when connected together, and hence the star point is also referred to as the neutral point. The star point *of a system* is often referred to, and while being quite correct to do this, the star point actually is formed by the common junction of the windings of the plant supplying the system. Star points are utilized for earthing purposes and for connexion to neutral conductors, for the supply to loads from each line terminal to the star point. *See* Earths.

STARTERS FOR MOTORS AND THEIR DESIGN

By C. C. Garrard, Ph.D., M.I.E.E., A.Am.I.E.E., and C. J. O. Garrard, M.Sc.

Since large motors cannot be started merely by closing a switch, the design, arrangement and use of starters is a subject of much importance. Here expert consideration is given to the subject in general terms. For details of each type of starter see the specific headings, as Auto-Transformer ; Contactor ; Drum ; Face Plate ; Liquid ; Star-Delta ; Switch, etc.

The current taken by a machine is limited by: (1) the resistance or reactance or both of the windings, (2) the back electro-motive force of the machine. Of these (2) is, of course, very much the greater. When the machine is stationary, however, (2) disappears, so that if the full voltage is applied to the terminals, practically a short-circuit current flows.



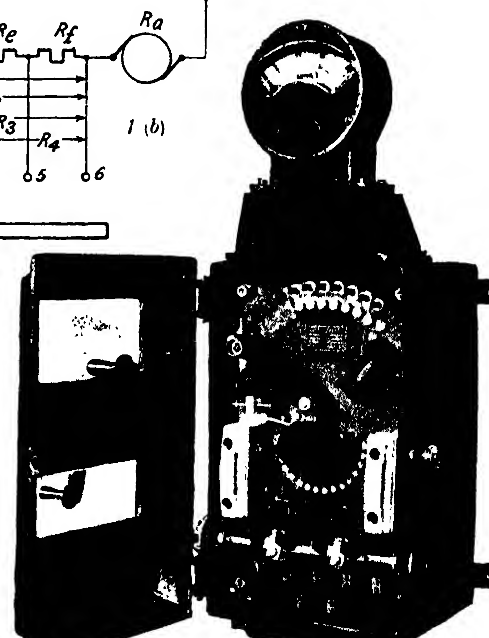
This is avoided by the use of starters, which limit the current during the running-up period while the back E.M.F. is building up.

Types of Starter. *Starters using Metallic Resistances.* These consist of metallic grids or wire spirals connected in series with the motor windings and cut out or short-circuited successively by a contact arm moving over a series of fixed contacts. For starting polyphase induction motors the resistances are usually in series with the rotor windings.

Liquid Starters. Here an electrolyte, such as washing soda solution, replaces the metallic resistances.

Transformer Starters. The starting current may be limited by applying a reduced voltage to the machine, which is increased to the normal value as it speeds up.

Miscellaneous Starters. These include star-delta and eddy-current starters.



STARTER. Fig. 1 Starting panel for D.C. motor with schematic diagram showing step by step operation. *General Electric Co., Ltd., of England.*

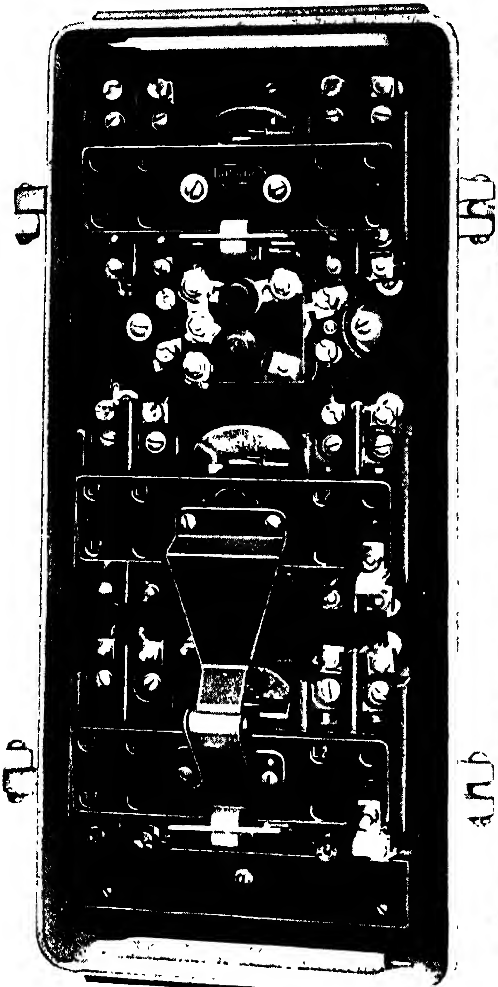


Fig. 2

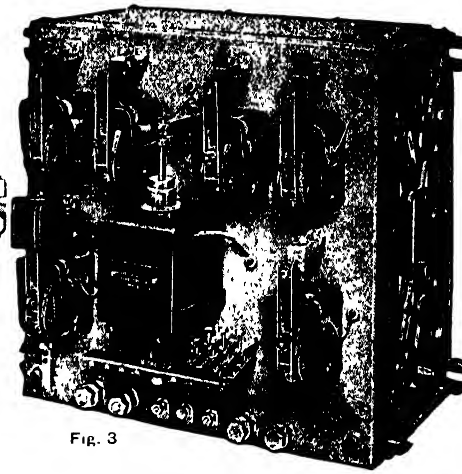


Fig. 3

Fig 3. A medium-sized multiple contactor starter.

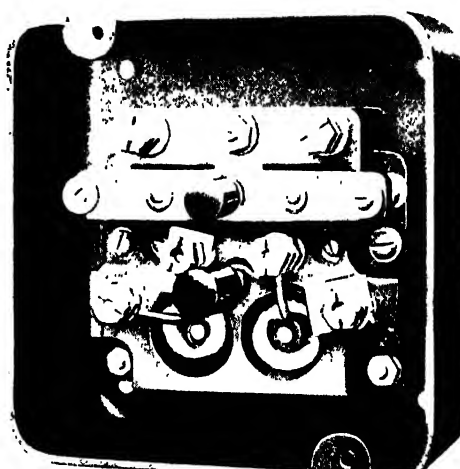


Fig 4

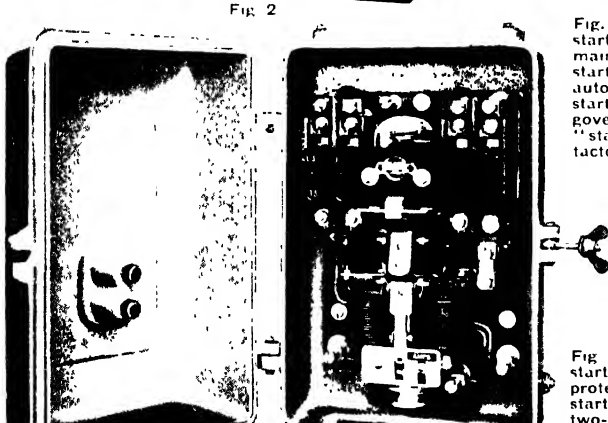


Fig. 5

Fig. 2 (top, left) An automatic star-delta starter. When the "start" button is pressed the main line contactor closes and connects the starter to the supply, immediately followed by automatic closure of the "star" contactor to start the motor. After a suitable pause, governed by the thermal timing device, the "star" contactor opens and the "delta" contactor closes automatically, thereby accelerating the motor to running speed.

Fig. 4. An across-the-line contactor-type starter with low voltage and thermal protection. Its application is for push-button or automatic starting and stopping of squirrel-cage motors and single-phase self-starting motors which may be switched directly to the supply lines. Maximum capacity is 7½ h.p., 380 550 volts, 3-phase.

Fig 5. An across-the-line automatic motor starter, with low voltage and magnetic overload protection It is a "push-button" automatic starter for single-phase self-starting motors, two-phase and three-phase squirrel-cage motors An automatic starting unit complete in itself, the "start" and "stop" push-buttons are incorporated in the case.

STARTERS: A SELECTION OF TYPES OF AUTOMATIC MECHANISMS

Courtesy Igranic Electric Co., Ltd (Figs 2, 4, and 5), and for Fig 3, Wm Geipel, Ltd

To face page

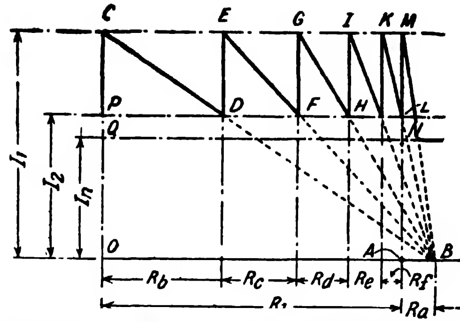
Starters Using Metallic Resistances

Face Plate Starters. This is the commonest type of construction for D.C. motor starters. The contacts are fixed on a slab of insulating material, on the back of which the resistances may conveniently be mounted. A pivoted arm carrying a contact at its extremity moves over the fixed contacts. The arm is held in the closed position against the pressure of a spring by means of a small electromagnet shunted across the supply. The starter is thus returned automatically to its zero position on a failure of the supply. In order to ensure that when starting up the motor sufficient time is allowed on each step for the motor to accelerate, "step by step" devices are used, *see* Fig. 1. They usually consist of some sort of a rack which allows the arm to move unobstructed from the on to the off position, but in the opposite direction necessitates the starter handle being rocked to clear the arm for its movement on to the next step. This type is illustrated in pages 488–89.

The correct operation of a starter depends in the first place on the proper "grading" or proportioning of the resistances in the various steps.

Grading of Shunt Motor Starters. In Fig. 1 (*b*) the steps of resistance R_b, R_c, etc., are shown, together with the moving contact K, which short-circuits them one after the other as it moves from left to right. The problem resolves itself into determining the values of R_b, R_c, etc., to accelerate the motor smoothly.

The maximum permissible value of the momentary current rush (I_1) on starting may be between $1{\cdot}5\ I_n$ and $2\ I_n$ where I_n is the normal full load current. If E is the supply voltage and R_a the resistance of the motor itself, then $R_1 + R_a = E/I_1$ where R_1 is the value of the first step of resistance and I_1 the maximum permissible current. On closing the supply switch with K at the extreme left-hand position, a current I_1 will flow. The motor will turn and the current will decrease as the back E.M.F. increases. As soon as the current has decreased to some arbitrarily fixed value, say I_2 (approximately equal to I_n), we may move the contact K to position 2. The resistance R_2 must now be such that the momentary rush of current is again I_1. A graphical construction for determining R_b, R_c, R_d, etc., is given in Fig. 6. This method necessitates a certain amount of trial and error, and is only approximate. The grading of starting resistances is largely a matter of experience, accurate calculation being frequently impossible.



STARTER. Fig. 6. I_1, I_2, R_1, and R_a represented by OC, OP, OA, and AB, are set out to a convenient scale. CB is drawn cutting across the line representing I_2 at D. DE is drawn vertically to cut the line representing I_1, EB is drawn and so on, until finally the line KB cuts I_2 at L, which is vertically above A. The line OA has been made to represent R_1; the sections PD, DF, FH, HJ, and JL now represent the values of R_b, R_c, R_d, R_e, and R_f.

Grading of Series Motor Starters. With a shunt motor, moving the starter blade from one contact to the next does not alter the back E.M.F. With the series motor, however, this is not the case; the increase of current on passing from one step to the next increases the back E.M.F. It follows that fewer steps are required for a series than for a shunt motor. Fig. 7 gives an approximate graphical method of grading, similar to Fig. 6.

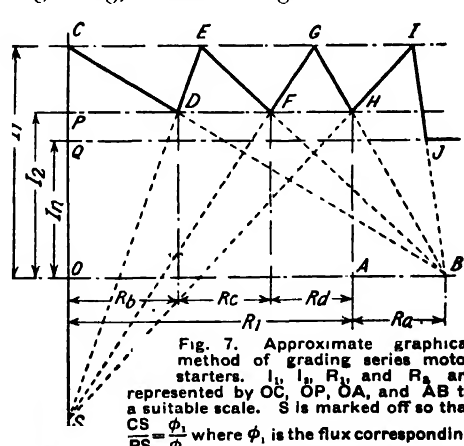
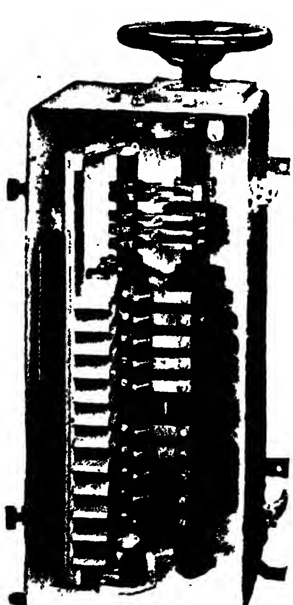


Fig. 7. Approximate graphical method of grading series motor starters. I_1, I_2, R_1, and R_a are represented by OC, OP, OA, and AB to a suitable scale. S is marked off so that $\frac{CS}{PS} = \frac{\phi_1}{\phi_2}$ where ϕ_1 is the flux corresponding to I_1 and ϕ_2 the flux corresponding to I_2. The construction is then similar to that of Fig. 6, except that the lines DE, FG, etc., pass through S instead of being vertical.

Influence of Load on Starter Characteristics. The above approximate methods of starter grading assume that the motors start up light; this, however, is by no means always the case.

Many applications of electric drive demand either that the motor shall start up under load (piston pumps, looms, lifts, etc.), or that it shall accelerate a considerable mass of rotating machinery (mill drives, machine shop shafting, conveyers, etc.) A third type of loading is that produced by fans and centrifugal pumps, where the load (apart from the inertia of the fan or pump rotor) is zero at the instant of movement from rest, but increases in proportion as the speed increases. Such circumstances must be taken into account in designing the starter, in order to ensure that the acceleration is uniform.

A further point to which attention must be paid is the rating of the starter. In some cases a motor is started perhaps twice a day or once a week; in others several times a minute. The current-carrying and heat-dissipating capacity of the resistances must be greater in the second than in the first case. Starters are usually specified to allow a certain number of successive starts against full load torque with a starting period of a certain length, without exceeding a certain temperature rise.



STARTER. Fig. 8. Interior of drum controller with blow-out coil and arc chutes. G E C, Ltd. of England.

Starters for heavy duty are frequently oil immersed; their capacity can thus be increased to almost any extent by increasing the volume of oil.

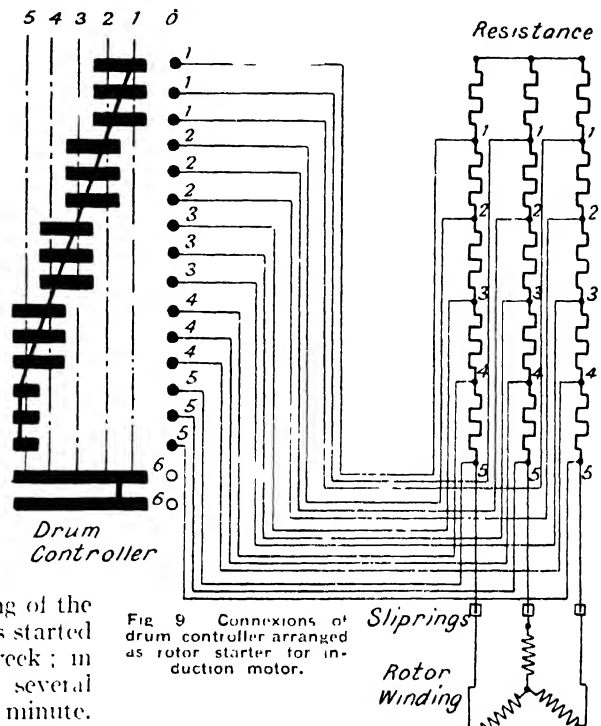
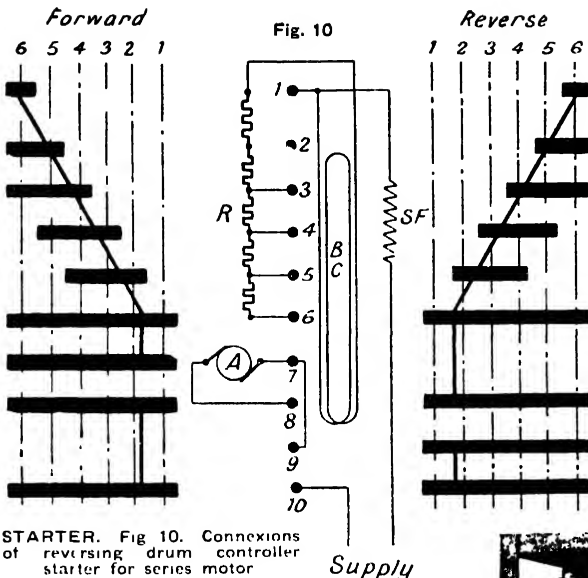


Fig 9 Connexions of drum controller arranged as rotor starter for induction motor.

Drum Type Starters. Instead of having a number of fixed contacts and one (or, in a three-phase starter, three) movable contact arm, we may have a number of fixed contact fingers and arrange the contacts to move under them. We then have a drum controller (*q.v.*), much used in traction work.

Fig. 8 is the interior of a typical drum controller, and shows the magnetic "blow-out." This is a coil carrying the load current which sets up a magnetic field perpendicular to the contact finger. The arc formed on breaking contact is thus blown away from its point of origin and quenched.

Fig. 9 shows the connexions of a drum controller used for starting an induction motor. This is a "developed diagram," *i.e.* the drum is represented as if its surface were rolled out flat, and is supposed to move from side to side underneath the fixed fingers represented by circles. Fig. 10 shows the connexions of a simple reversing controller for a series motor.



STARTER. Fig 10. Connexions of reversing drum controller starter for series motor

For heavy service, as in rolling mill and crane drives, the controller drum is used merely as a control organ, the circuit being made and broken by contactors. We have, then, contactor starters (*q.v.*), the design of which presents no particular problems apart from those connected with the design of the components.

Lock-out Devices. In order to keep the starting current within the prescribed limits, a pause must be made on each step of the resistance to give the motor time to accelerate. The time required may vary considerably on different occasions, so that if it is left to the operator's judgement he is liable to advance the controller too quickly. To guard against this the contactors are provided with coils which, when energized, hold them open. Each of these coils carries the current of the contactor preceding it in the order of closing, as is shown in Figs. 11 and 12. The result is that contactor 2 cannot close until the current in the first step has fallen to a prescribed value, and so on.

For small shunt motors a vibrating relay is used, the coil of which carries the motor current. The motor starts up with its field resistance in circuit, but immediately the current exceeds a certain value the relay closes, increasing the field and reducing the current by short-circuiting the field resistance. The relay vibrates until the motor attains its normal speed (Fig. 13).

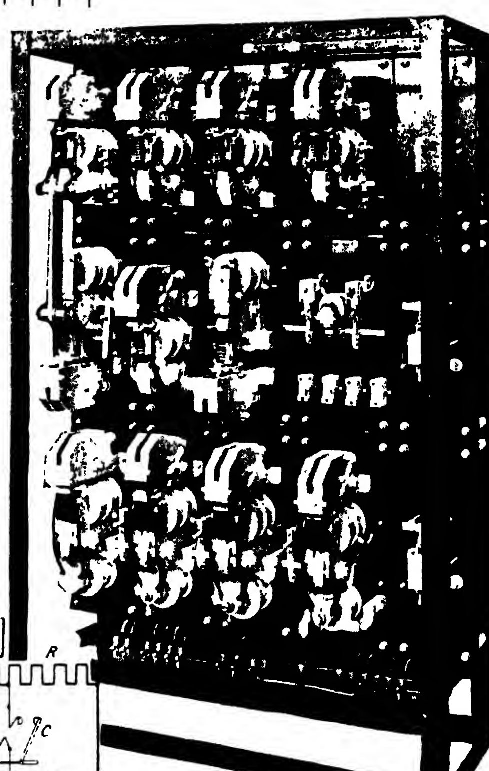


Fig 11

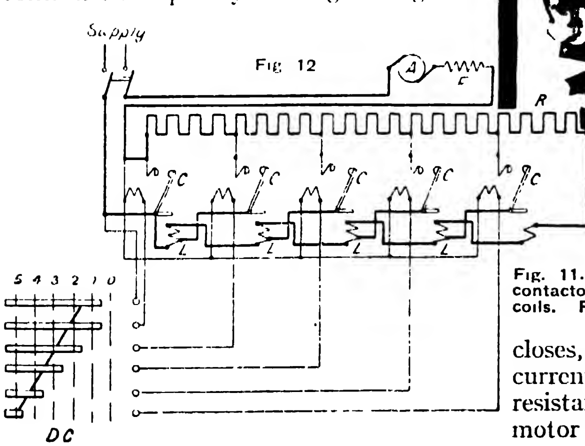


Fig. 11. A contactor starter: the bottom row of contactors being provided with current lock-out coils. Fig. 12. Schematic arrangement of Fig. 11. *G E C., Ltd, of England*

Automatic Starter. Instead of a drum controller, we may use a retarded relay to operate the contactors (Fig. 14). Here a bar is pulled up against a series of fixed contacts by means of a solenoid, its movement being retarded by an eddy current brake. Each contact controls a contactor, so that these are closed one after the other in series. The last contactor to close breaks the supply to all the others and at the same time cuts off the current to the retarded relay so that this resets itself and is ready for the next start.

STARTER. Fig. 13. A vibrating relay used for starting a shunt motor.

Such starters may be controlled by push-buttons which allow starting or stopping from any number of separate stations.

Rotor Starters for Polyphase Induction Motors. If E_r is the rotor phase voltage of an induction motor and R the rotor resistance, the momentary current induced in the rotor on switching on will be

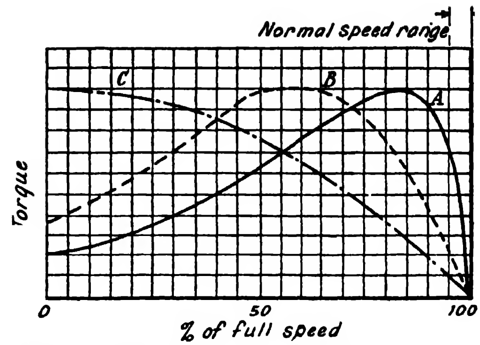


Fig. 15. The curve A represents the variation of torque with speed with the slip-rings short-circuited. Torque is small on starting, rises to maximum and falls again to zero at synchronous speed. If resistances be now inserted in the rotor circuit the curve B is displaced towards the left. If resistance is increased still further we arrive at a value such that the maximum of the curve C is when the speed is zero.

$I_r=\frac{E_r}{R}$. The corresponding stator current (with locked rotor) will be

$$I_s=\frac{E_r}{R}\times\frac{E_r}{E_s}$$

where E_s is the normal stator voltage. The stator current is thus inversely proportional to the rotor resistance, neglecting, of course, the magnetizing current and the reactance of the motor. We can therefore reduce the starting current by resistances in series with the rotor. The most favourable value of resistance is such that the maximum of the speed torque curve (Fig. 15) occurs when the speed is zero. Its value is the difference between the rotor resistance and reactance (referred to line frequency).

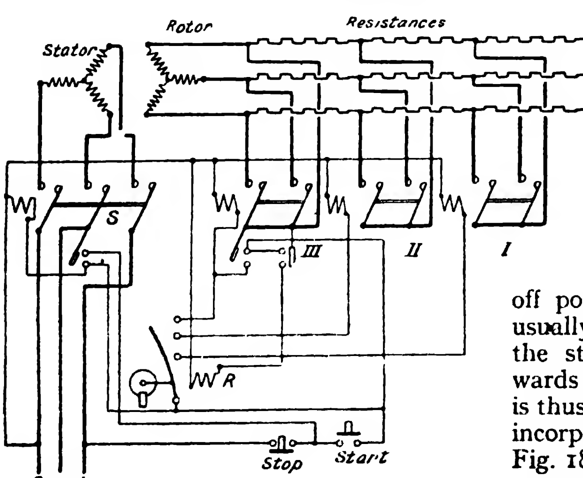


Fig. 14. Connexions of automatic contactor starter with retarding relay.

The construction and grading of starters for three-phase motors is similar to that for D.C. motors, except that three sets of resistances and three sets of contacts become necessary; the magnetic release is, however, not used. It is therefore customary to interlock the starter with the main switch so that this cannot be closed unless the starter is in the off position; in addition, a contact is usually provided which trips the switch on the starter commencing to move backwards; arcing at the contacts of the starter is thus avoided. An oil-immersed starter incorporating these features is shown in Fig. 18.

Unequal Grading of Starting Resistances. In order to increase the number of

steps, one may grade each phase differently and arrange the starter contacts so that the steps are not changed simultaneously on all three phases, but on one after the other in cyclical order. The resistance steps are then chosen so that if they were all on one phase they would each give an equal change of speed.

Miscellaneous Starters

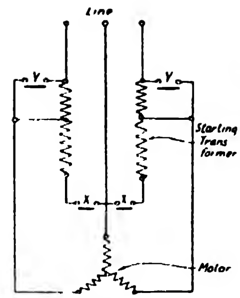
Liquid Starters. The amount of power dissipated by a starter increases rapidly with the size of the machine, and with very large motors which are started frequently (blooming mill drives, mine hoists) the use of metallic resistances would lead to a very bulky and expensive construction. The use of an electrolyte as resistance provides a solution to the difficulty; the high specific heat of water enables it to absorb large quantities of heat, and in addition the electrolyte can easily be cooled. There are two methods of construction, both of which are illustrated in the Plate facing page 772.

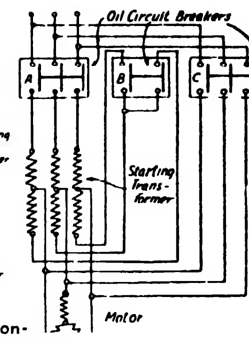
Fig. 18. Interior construction of an oil-immersed rotor starter.
G E C., Ltd., of England

In the first the fixed electrodes are mounted in insulated pots at the bottom of an iron tank. In the second the electrodes may be fixed and the level of the electrolyte varied, as by pumping the electrolyte continuously over a weir the height of which can be varied. *See further under* Liquid Resistances.

Transformer Starters. These are much used, particularly for H.T. motors; it is easy to provide the transformer with tappings, the most suitable of which can be chosen for each application.

In the interests of economy auto-transformers (*q.v.*) are invariably used,





STARTER. Fig. 19. Connexions of auto-transformer starter where supply to motor is not broken during change from starting to running position. For starting, XX are closed and then opened and YY are closed.

Fig. 20. Scheme of auto-transformer starter using three mechanical interlocked oil circuit breakers. Sequence of operations: close A, close C and at same time open B and subsequently A.

often in V connexion, which needs only two phases; oil immersion is usual.

It is advantageous if the connexions to the tappings and the tapping switches are so arranged that the circuit to the motor is not broken in changing over from the starting to the running position. This can be done by the arrangement shown in Fig. 19. The contacts XX are opened before those at YY are closed. Fig. 21 shows the diagram of connexions of a

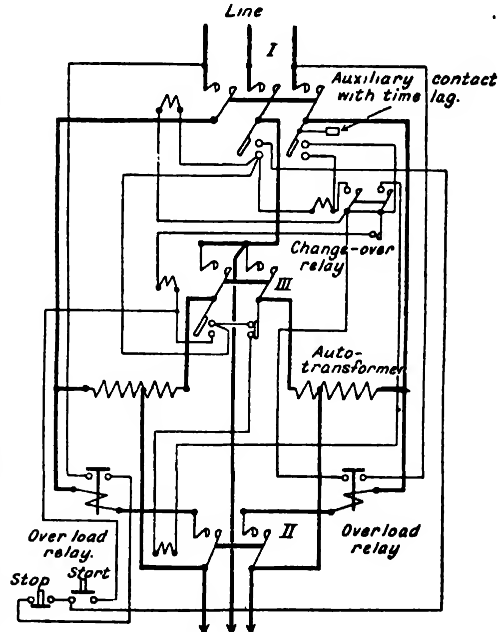


Fig. 21. Contactor operated auto-transformer starter. Sequence of operations: III closes, I opens, pause, III opens, II closes.

transformer starter using contactors and controlled by push-button. Fig. 20 is a scheme used for large motors in which the change-over from the starting to the running position is made by means of three mechanically interlocked oil switches. Closing switch A connects the motor in series with the transformer windings; B closes the neutral point of the transformer and applies the tap volts to the motor. On closing C, B is automatically opened, and subsequently the transformer is short-circuited and the motor connected to the line. A further interlock opens A.

Star-Delta Starter. This is an extremely simple and useful starter for three-phase (squirrel cage) induction motors of moderate size (Fig. 22 and illus. page 1143).

The motor is wound for operation with its windings connected in delta (Fig. 23). During starting the phases are connected in star, so that the voltage applied to each phase becomes $\frac{E}{\sqrt{3}}$ where E is the line voltage, and the current is correspondingly reduced.

The connexions may be changed over by contactors, in which case the starter may be operated by a push-button.

Where star-delta starters are used for motors which are protected by fuses it is desirable to cut these out during starting, so that they do not blow with the rush of current. In the running position the fuses should be outside the delta, as in Fig. 23 (B), and not inside, as in Fig. 23 (A). The connexion in Fig. 24 ensures this.

Eddy Current Starter. When the rotor of an induction motor is stationary, the frequency of the rotor current is that of the supply. If a choke coil with a solid core is connected across the slip-rings the impedance of its windings will be high, because of the eddy currents induced in the core. As the motor speeds up, the frequency of the current and the impedance of the windings decrease, until at full speed the impedance is negligible. This form of starter is used to some extent for small motors.

STARTING MOTOR (in Motor Cars). The internal combustion engine must be rotated either by hand or from some independent source of power before it will begin to function. To this defect is due the inclusion of an electric starter motor or a dynamotor as standard equipment on practically all motor cars.

Electric charging and starting systems on motor cars are of the single-unit or of the two-unit type, the latter being more widely used.

In the single-unit system, a single machine, known as a dynamotor (*q.v.*), operates either as a dynamo for the generation of current to charge the battery or as an electric motor when it is necessary to start the engine, current being then supplied from the battery. In two-unit systems, the

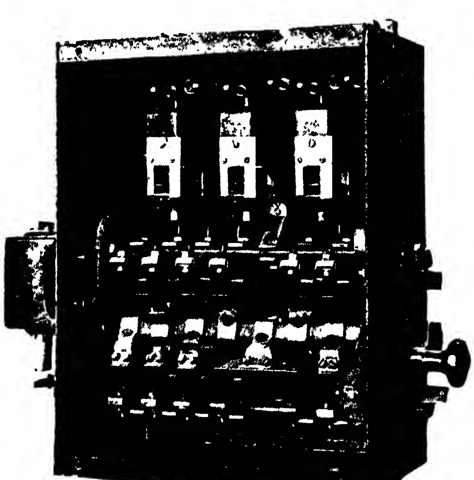
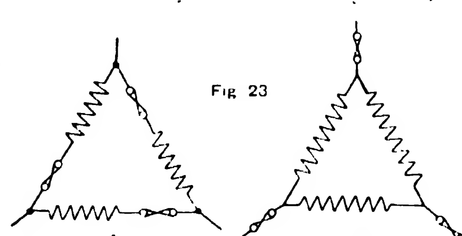


Fig. 22



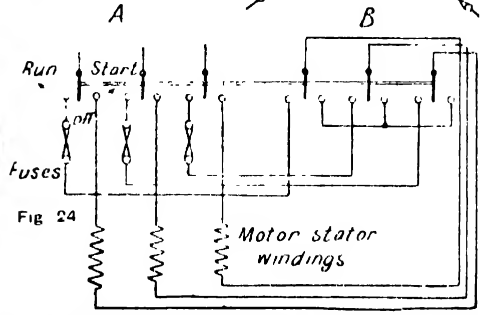


Fig 24

STARTER. Fig. 22. A G.E.C. star-delta starter. Fig. 23. Wrong method A and right method B for fuse connexion. Fig. 24. An arrangement providing for Fig. 23 B. (Other illustrations are in p. 1143.)

dynamo is driven continuously from the engine, and the starting motor is geared to the flywheel of the engine only when necessary. A toothed pinion on the end of the starter armature shaft automatically enters into engagement with a toothed ring secured to the periphery of the flywheel, and is rotated at high speed when the current is switched on.

Starting motors are usually of the four-pole series-wound type, capable of exerting a high torque when rotating slowly, or rotating at high speed when lightly loaded, and being thus particularly adapted for starting purposes. Such motors rarely give trouble and are therefore liable to be neglected It is important, however, that the brushes should be kept clean and work freely in their guides and the commutator must be perfectly smooth and free from any deposit of carbon or oil. There is always some risk of electrical connexions on parts subjected to vibration working loose, and the starter connexions should occasionally be inspected *See* Dynamotor, Motor Car, Electrical Equipment.

STARTING RHEOSTAT. A variable resistance included in the circuit of electric motors for obtaining a gradually increasing current necessary in starting a motor of any size Considerably more current is required to begin the running of a motor than is required to maintain its speed once acquired. This excess of current would result in damage to the motor windings if a motor-starter were not fitted Essentially, the starter consists of a number of resistances, which are cut out of the circuit as the starter handle is advanced over a number of radial studs. *See* the heading Starter for details of design of the different types of starter.

In a shunt motor the current I is driven by the supply voltage E against the back E.M.F. e and

$$I = \frac{E - e}{R_a}$$

where R_a is resistance of armature windings. With the machine stationary $e = O$, and if the full voltage were applied to the stationary armature an excessively large current, perhaps twenty times as great as the full load current, would flow. An overload release incorporated on the starter affords protection against this possibility, and a suitable starting resistance is inserted in the armature circuit to maintain the value of the armature current at a reasonable figure. As the speed of the motor increases with resultant increase in the value of the back E.M.F. the resistance can be gradually cut out.

For a shunt motor the acceleration is proportional to the armature current. The starting current must produce a torque sufficiently large to overcome the frictional resistance of connected machinery and leave a margin to produce adequate acceleration. The maximum value of the starting current is limited by :

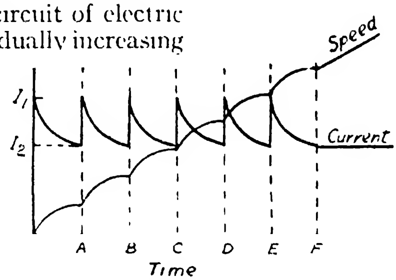
(*a*) Carrying capacity of fuses, etc.

(*b*) Disturbing effects on neighbouring circuits

(*c*) Necessity of preventing damage to connected machinery or machine itself due to excessive acceleration.

(*d*) Sparking at the brushes and resultant flash-over.

(*e*) In traction the torque produced must not be sufficient to produce slip in the driving wheel of the vehicle.



STARTING RHEOSTAT A, B, C, D, etc., mark intervals at which radial arm is moved over to next resistance stud.

In the diagram I_1 is the maximum value of the starting current and I_2 the minimum value, usually rather greater than full-load current. If R_1, R_2 and R_3, etc., are resistances on respective studs, and n the total number of studs, then at start

On 2nd stud end $I_2 = \frac{E - e_2}{R_2}$

On (n-1)th stud start $I_1 = \frac{E - e_{n-2}}{R_{n-1}}$

" " " end $I_2 = \frac{E - e_{n-1}}{R_{n-1}}$

On nth stud start $I_1 = \frac{E - e_{n-1}}{R_a}$

" " " end $I_2 = \frac{E - e_n}{R_a}$

and the curve becomes horizontal

By simple division we see that

$$\frac{I_1}{I_2}=\frac{R_1}{R_2}=\frac{R_2}{R_3}=\frac{R_{n-1}}{R_n}$$

and by multiplying all these equations

$$\frac{R_1}{R_n}=\left(\frac{I_1}{I_2}\right)^{n-1}$$

and from these two equations n the number of resistance steps necessary in starting up the motor can easily be calculated.

STARTING SWITCH. A device used for starting up large direct-current machines by connecting a number of resistance elements successively in parellel, as shown by the diagram of connexions (Fig. 1). It consists of a series of knife switches each connected to a resistance element, and closed one after the other by hand; the order of closing in Fig. 1 is from left to right. Fig. 2 shows a typical starting switch. The operator is prevented from closing the switches in any order but the correct one by means of a notched interlocking bar. As each switch is closed the bar is moved along a short distance, thus allowing the next but no other switch to close.

The resistance unit at the extreme left has a high resistance and small current-carrying capacity; the combined resistances of the units decrease and their current-carrying capacities increase as the switches are closed in parallel with one another from left to right, corresponding to the increasing current as the machine starts up. The last switch on the right is a short-circuiting switch and must carry the full load current continuously.

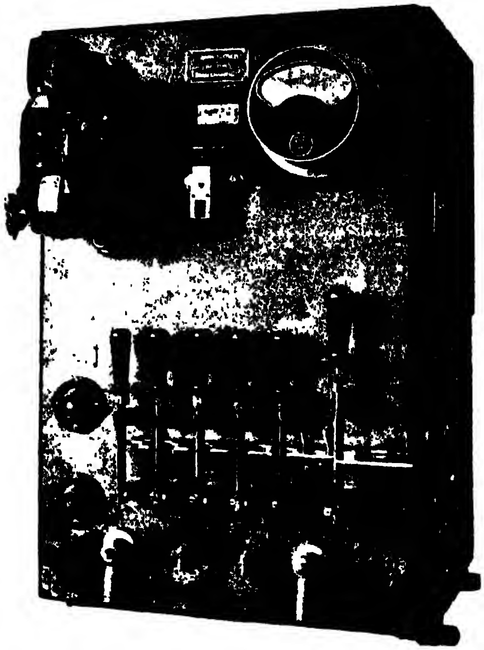
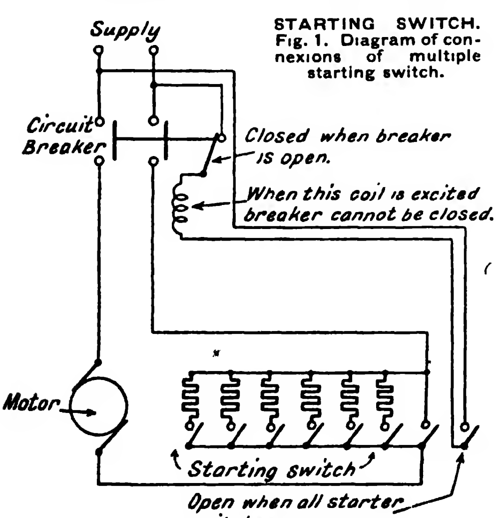


Fig. 2. Multiple starting switch, showing interlocking bar and interlocking contacts. The contactor on the upper part of the board is used as overload protection.

General Electric Co., Ltd. of England.



STARTING SWITCH. Fig. 1. Diagram of connexions of multiple starting switch.

In order to prevent the circuit breaker being closed when the starting switch is in the closed position, which would result in a short circuit, an interlock is usually provided. This may consist of a contact on the starting switch, which is closed when the circuit breaker is open, and a hold-off coil on the circuit breaker, which, when it is energized, prevents the breaker from being closed. All these are connected in series as shown in Fig. 1. When the breaker is open, closing one of the starting switches energizes the hold-off coil and prevents the breaker being closed. *See* Starter.

STAR VOLTAGE. The term star voltage is used to designate the voltage from a line terminal to the neutral point of a star-connected polyphase A.C. system of windings or conductors. The proper term is phase voltage, but as the latter is often loosely (and erroneously) applied to the line-to-line voltage, ambiguity is avoided by the description " star voltage." The relationships between star voltages

and line voltages for balanced A.C. polyphase systems are as follows :—

Three-phase : 1 to 1·73
Four-phase : 1 to 1·41
Six-phase : 1 to 1 for vectorially adjacent line terminals.
1 to 2 for vectorially diametric line terminals.

If the potential of the star neutral point is not zero or if the line voltages become unbalanced, the above ratios are altered to an extent depending upon the degree of unbalance present.

Star voltages may contain considerable harmonic components, principally the third, if steps are not taken to reduce them to negligible proportions, by avoiding high magnetic induction densities in iron-cored plant and apparatus or by providing means, such as a delta winding on a transformer, for short-circuiting the harmonic voltages. The voltage ratios mentioned above also are affected by the presence of harmonics in the respective wave forms. *See* Star Connexion.

STAR-WOUND REACTOR. A star-wound reactor is more properly called an interconnected star reactor and it is used for obtaining a star point artificially for earthing a delta-connected A.C. system. Such a reactor may be designed to have a low or a high impedance, depending upon whether current limiting resistances are used in conjunction with it or not. The reactor is described more fully under the heading Neutral Earthing Compensator (*q.v.*).

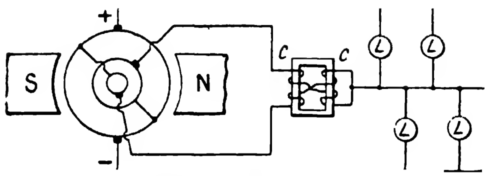
STASSANO FURNACE. A type of arc furnace in which the arc is struck between electrodes, two, three, four or six electrodes being employed according to the size of the unit. The furnace usually consists of an eccentrically rotating cylindrical chamber of steel lined with dolomite or other refractory material. The rotation ensures thorough mixing of the molten ores and the metal and slag are run off through a tap provided. Water-cooled electrodes with hydraulic regulation for adjustment of feed are incorporated on the larger sized furnaces. An average energy consumption for a 1-ton furnace would be of the order of 1000 B.T.U. per ton of steel.

STATIC. Static is the name rather loosely given to the manifestations of electrical discharges in the atmosphere, to accumulations of atmospheric electrical charges on exposed insulated conductors and to frictional electrical charges such as arise in connexion with paper-making machinery and the passage of leather and similar belts over pulleys. Perhaps the most familiar example of "static" are the noises in radio receiving sets which range from low noise-intensity crackling to cannon-like reports.

To the power electrical engineer "static" is familiar as more or less high intensity electric charges on overhead lines produced by changes in elevation of the lines, sandstorms, nearby clouds, wind and rain, these creating high voltages to earth on the lines with all their concomitant dangers (*see* Electrostatic Interference under the heading Capacity, p.186). To the communication circuit engineer "static" further visualizes the possibility of high induced voltages on telegraph and telephone lines arising from the proximity of high voltage power lines, unless steps are taken to counteract their effects.

"Static" is thus associated with the presence of electric charges and potential differences which are related by the expression $Q = CE$ where Q is the electric charge, C is the circuit capacitance and E is the potential difference established by the charge. The discharge of an accumulation of "static" electricity results in the flow of current which produces wireless receiver "atmospherics" and surge currents in power circuits. *See* Atmospherics ; Capacity ; Electrostatic Field ; Surge.

STATIC BALANCER. To equalize the voltage between the wires of a three-wire A.C. or D.C. system when fed by a single generator across the outers, a static balancer may be substituted for the rotary balancer set described under Balancer (*q.v.*). The diagram illustrates the simplest form of single-phase balancer in which two slip-rings tap the armature winding at points 180 electrical degrees apart. Each slip-ring is connected to one end of a pair of coils of low ohmic resistance and high inductance wound on a laminated iron core. These coils act as chokes to the alternating voltage impressed on them by the generator, and if joined at the other ends to the neutral wire, their common terminal will have always a voltage



STATIC BALANCER. The choke coils CC are specially wound so that there is no out-of-balance flux and the main flux is not disturbed. Lamps LL constitute balanced load.

midway between that of the slip-rings, *i.e.* midway between the voltages of the brushes. For a balanced load no neutral current flows and the choking coil takes only a small magnetizing current. When the load is unbalanced, the currents carried by the positive and negative brushes respectively are unequal and the out-of-balance current will return *via* one of the pair of choking coils according to the position of the slip-rings at that instant.

The currents actually flowing at any moment may be regarded as made up of an alternating component which traverses the coils in series and a D.C. component of the out-of-balance current, which is the difference between the currents in the two outers. This difference varies according to the relative position of brushes and slip-rings, as does the potential of the middle wire from its correct value midway between the potential of the brushes. When the tappings are midway between the brushes each of the coils carries half the out-of-balance current, the current in one coil opposing the magnetization that would be induced by the current in the other coil so that only the alternating flux due to the alternating current remains in the closed magnetic circuit.

The coils are connected as shown in such a manner that the out-of-balance component cannot produce a flux whilst the main flux is undisturbed.

A 4- or 6-phase star-connected coil may also be adopted, whilst 3-phase star employing three slip-rings is a common connexion. Increase in the number of phases renders the armature current distribution more even with consequent decrease in local heating due to the out-of-balance current. *See* Converter.

STATIC CHARGE. A charge impressed upon a body (not necessarily an electrical conductor) due to condenser action, in which a state of electric strain acts through a dielectric (*q.v.*) to produce electric charges of opposite sign at the extremities of the system. The term is an abbreviation of electrostatic charge. This charge is produced by subjecting the atoms of the body to a tension which cannot be released until either the body touches another not similarly charged, or through a disruptive spark, as with lightning (*q.v.*) or an oscillatory discharge (*q.v.*)

A static charge may be induced by friction, difference of temperature, molecular disintegration, or contact electrification of electrically insulated bodies. Its strength is proportional to the dimensions of the body, the impressed force, distance separating the charged body from any other (*see* Oscillatory Discharge), and the nature of the separating medium (*see* Dielectric Constant).

A static charge, like a magnetic pole, will repel another similar charge and attract an opposite charge, according to Coulomb's Law (*q.v.*). The line diagrams representing these conditions are similar to the conventional iron filings figures of magnetism. *See* Atmospheric Electricity; Electrostatic Field.

STATIC-FREQUENCY-CHANGER. The more usual type of frequency changer comprises a rotating synchronous motor coupled direct to an alternator wound for the frequency desired (*see* Frequency Changer). There is, however, a static type of frequency changer, in which no moving parts are employed, formerly used to some extent in wireless telegraphy and of occasional application in power work. It consists essentially of a 3-phase transformer whose secondaries are connected as for mesh, but opened at one point. A voltage is set up equal to three times the third harmonic of each secondary and having three times the frequency of the primary supply.

In another type, the transformer core receives additional magnetization from an auxiliary D.C. source and is designed to work at a much higher flux density than normally employed, this flux varying between maximum and zero instead of alternating in the usual manner. The varying magnetic permeability at the high flux densities sets up harmonics in the secondary and a voltage is produced at double the original frequency. Such

an arrangement is of use in traction lighting where a low-frequency supply is available for the driving motors, but is not adopted to any extent in this country.

STATIC TRANSFORMER. An alternating current device for transforming energy from one voltage to another without change of frequency. Usually described as a transformer (*q.v.*).

STATION LOAD FACTOR. A quantity of importance in the estimation of the charge to be made to consumers in the district supplied by the station. In addition to the actual cost of the electricity used by the consumer, the latter is also expected to pay his share of the capital and overhead charges involved by the initial outlay on mains, generators, switchgear, etc. All these must be of sufficient capacity to supply the total maximum demand which might be required by all the consumers at any one time. The relationship between the running costs and the standing charges depends therefore, to a certain extent, on the ratio between the number of units of electrical energy sold and the maximum simultaneous load on the feeders during the supply period. Or expressed as a percentage :

$$\text{Load Factor} = \frac{\text{Average load during period} \times 100}{\text{Maximum load during period}}$$

$$\text{Station Load Factor} = \frac{\text{Net kWh output per day} \times 100}{\text{Net Max hours load in kW} \times 24}$$

This must not be confused with the plant load factor which is based on the rated capacity of the plant.

$$\text{Plant Load Factor} = \frac{\text{Average hourly load for year} \times 100}{\text{Aggregate rated cap. of installation}}$$

Maximum station efficiency would be attained with a load factor of 100 as the plant would then be running to full capacity. This, of course, never occurs in practice, though astonishingly high figures are attained in modern power-stations. *See* Load Factor ; Maximum Demand.

STATORS IN ALTERNATORS AND MOTORS

By Arthur Arnold, A.M.I.E.E., A.M.I.Mech.E.

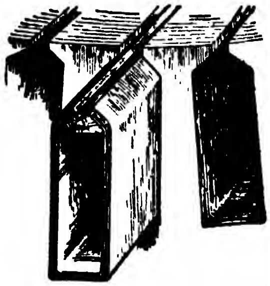
This article, which is complementary to that on Rotor, is concerned with the frame, core and windings of the stationary part of A.C. motors and generators. The main articles on both—particularly that on Alternators—should obviously be consulted. See also Armature; Electro-Magnetic Machines; Generator, D.C.

That part of an electro-magnetic machine which does not rotate ; usually employed only with reference to A.C. machines, whether motors or generators.

A stator has three principal parts, the frame or casing, the laminated magnetic core, and the windings in slots in the core. The frame may be of cast iron, cast steel, or welded wrought steel, the latter being utilized in modern designs to save weight and space. The core is dovetailed and clamped, sometimes with through-bolts to the frame, end pieces at either side of the laminations being sometimes made of non-magnetic metal. Windings are variously connected, according to the type of machine, and are carefully insulated within slots around the inner periphery of the core. The only exception is the rotating armature alternator in which the stator is constructed on similar lines to the yoke and field frame of a D.C. generator. Such machines are unusual and only found in small sizes.

Stator Design. Stator proportions vary a great deal with the speed of the machine, being governed by the allowable peripheral speed of the rotor. Thus for slow-speed machines the stator, like the rotor, is of large diameter compared with its axial length, whereas for high speeds the length may be greater than the diameter. In slow-speed machines, which are usually of the open type, the problem of ventilation of the stator hardly arises, but in compact high-speed machines it is of first importance, and the frame may be specially arranged to provide inlet and exit ducts for the air. In large diameter stators the frame is usually split horizontally to facilitate erection and dismantling, and sometimes may be split also vertically. Turbo-alternator stators, however, are not usually split, and the great length of the rotor may necessitate special arrangements for its withdrawal.

As far as the core dimensions are concerned there is no difference between high-



STATOR. Fig. 1. Slot insulation of "Maxtorq" motors. The slots are lined with a moulded mica trough covered with leatheroid.

Fig. 2. Former-wound groups of coils, each group being jointless.

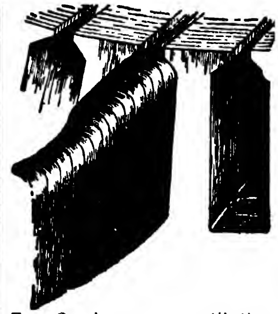


Fig. 3. In open ventilation machines, each coil is bound separately with tape which is wrapped over the wires, over the projecting slot lining.

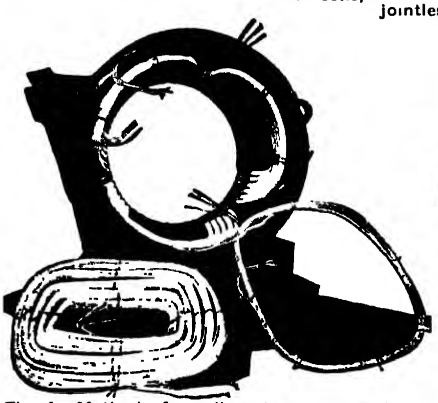


Fig. 4. Method of winding the stator is clearly shown.

Fig. 5. Completed stator of "Maxtorq" motor with four coils per group.

Figs 1-5 by courtesy of Lancashire Dynamo & Crypto Co., Ltd

speed alternators and synchronous motors of the comparable ratings, but the end turns of the windings of alternators require to be strongly braced to avoid ill-effects from the mechanical stresses caused by heavy short-circuit currents. The casing and core clamping plates must, therefore, be designed to take stout bolts for this bracing service. Additional insulation is provided on the end turns themselves and they are separated by hardwood spacers; the effects of thermal expansion must, nevertheless, not be overlooked. In motors it is unusual to provide end-turn bracing, except in those designed for exceptionally heavy service. The methods of insulating conductors in slots are discussed under Armature Winding (*q.v.*).

Bearings and End Shields. In alternators it is usual practice for the rotor bearings to be carried upon separate pedestals, but the bearings of motors are frequently supported from the end shields. These are generally spigoted to fit into a machined socket around the stator main frame, and thus the bearing position is definitely located centrally in the core space. In some cases means are provided for adjusting the bearing position at the spigot and socket; in others the bearing shell itself can be adjusted relatively to the end shield. Inspection holes, closed normally if necessary by plugs, are sometimes provided in end shields for the insertion of feelers into the air-gap.

In induction motors, where the air-gap is kept as short as possible, ball or roller bearings are frequently utilized in machined end shields. End shields carrying ring-oiler bearings are also often attached by set-screws so spaced that the end shield can be rotated through 90 or 180°, so permitting the motor to be attached to a vertical wall or to an overhead beam.

End shields of turbo-alternators are sometimes made of non-magnetic material,

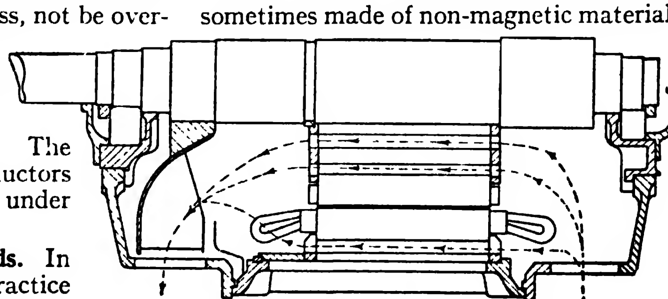
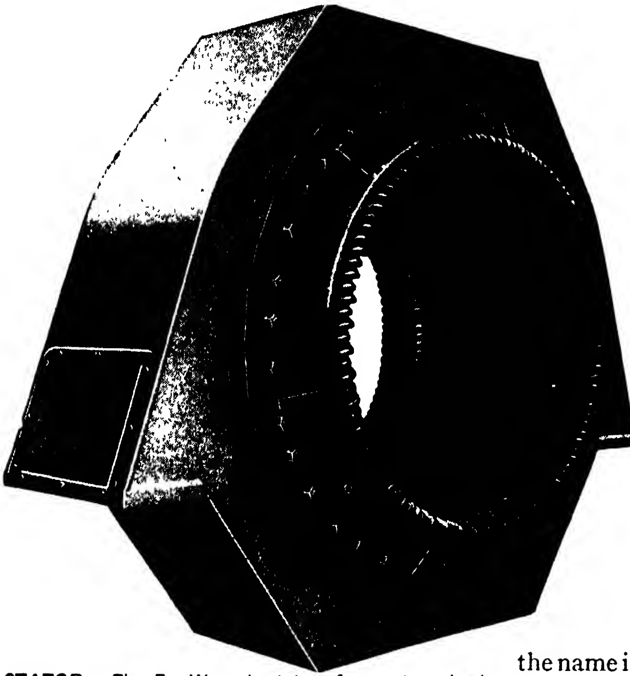


Fig. 6. Section of Type "R" squirrel-cage induction motor showing ventilation system.
Metropolitan-Vickers Electrical Co., Ltd.



STATOR. Fig. 7. Wound stator for water-wheel driven A.C. generator.
The British Thomson-Houston Co., Ltd

because they are in relatively close proximity to the end turns of the winding and may have eddy currents induced in them thereby. The non-magnetic construction does not cut out the eddy current losses, but makes them lower than they would be in iron or steel. In some stators a closed squirrel-cage winding is provided opposite the rotor end windings to minimize eddy current effects.

Frame Design and Ventilation. The detail designs of frames and end shields are varied to secure different types of enclosure. In open-type machines the end shields are merely spokes to carry the bearings. Protected-type machines have expanded metal or similar screens to fill in between the spokes. Drip-proof motors have end shields fitted with louvres and some additional outer cover around the core. Enclosed motors, as the name implies, have no openings through which ventilating air can enter or discharge from the interior. They therefore frequently have ribbed frames in order to increase the surface from which to radiate the heat corresponding to the motor losses. This device does not, however, prevent an

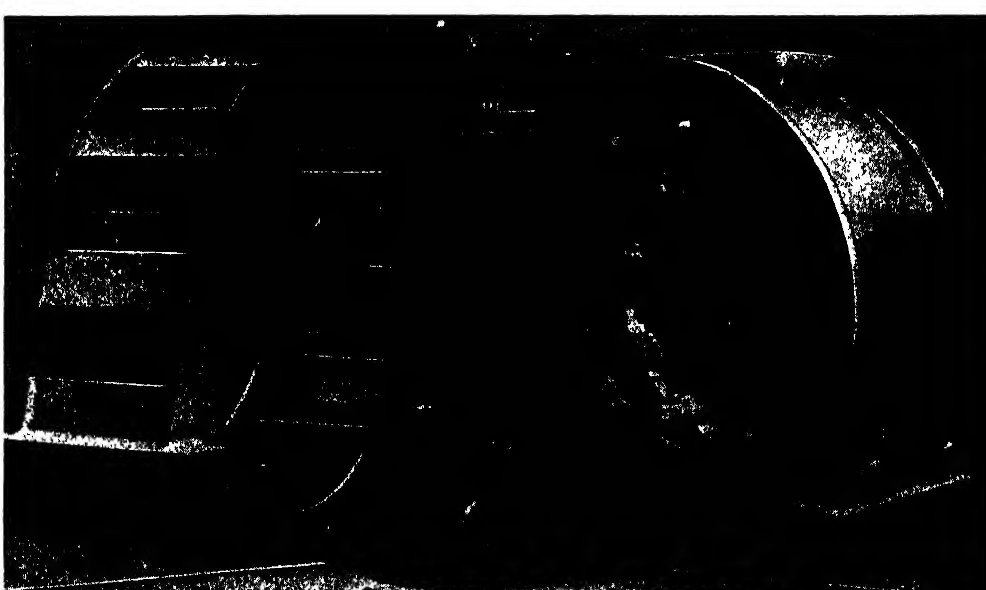


Fig. 8. Two motor yokes, one of cast iron and one of welded steel construction.
The Metropolitan-Vickers Electrical Co., Ltd.

enclosed motor being of necessity much larger, for a given rating and temperature rise, than one normally ventilated, and in consequence there are numerous special designs available in which additional radiating surface is provided, either separate from or built into the frame. In certain motors two fans are provided, one circulating the internal air through ducts which are cooled on the outside by external air blown against them by the second fan.

An alternative to an enclosed machine, permissible in certain circumstances where otherwise such a type would be necessary, is the pipe-ventilated motor, which is cooled by air drawn through ducts from the atmosphere at some distance, and possibly returned by similar means. By the provision of a filter on the inlet to a pipe-ventilated machine, the interior can be kept fairly clean, but this is a feature in which the enclosed motor naturally excels. In all other types it is essential to blow out the dirt.

The frames of turbo-alternators are specially adapted, in most cases, to provide for a closed air circuit through the machine and through a water-cooled radiator surface in series, the latter generally being arranged in the alternator foundation block. *See further under* Alternators.

Explosion-proof motors form a special class of machine. They are, naturally, totally enclosed, and all flanged joints are machined and specially wide. In some cases relief flanges are fitted, as to explosion-proof switchgear, with the intention of relieving any internal pressure that may be formed, but the width of the flanges suffices to prevent the egress of flame. Steel-works motors are another special type and usually have rectangular cast-steel frames, but they are ordinarily of the direct-current type because of the necessity for ready speed control.

Stator frames are provided with means for lifting, except in very small machines. The lugs or eyebolts are normally heavy enough to lift the motor with rotor complete. Recommended design and dimensions are laid down in British Standard Specification No. 529 (1934). Lifts should always be taken in a line direct with the axis of an eyebolt ; if two eyebolts are provided, a stretcher bar should be used to ensure this, or at least a long sling should be used, so as to avoid putting any appreciable sideways stress on the eyebolts.

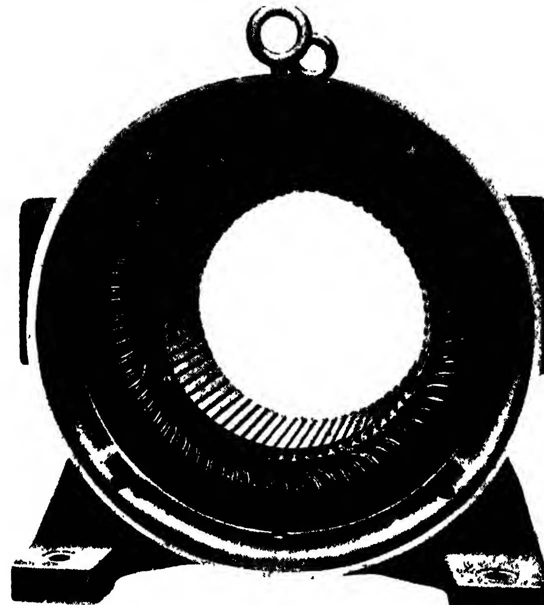
Terminal boxes are normally mounted at the side of the stator frame and are of varied design. Special care has to be taken with totally enclosed motors and with explosion-proof designs to secure proper sealing of the conductors at this point. In a few cases cable trifurcating boxes are also mounted direct upon the stator frame.

Stator Core Design. Core construction is described under the heading Alternator (*q.v.*). It is practically standardized for all types of machines, the only variations being those made by different designers in the methods of insulating the core stampings and in the types of ventilating spacers employed. In some special motors the slots are slightly skewed in the stator as well as in the rotor, but this is unusual. It involves special care in the stamping and in the assembly of the core. Induction motor stator windings are precisely similar to those of alternators. Repulsion and other special types of motor have, in general, cores of the normal kind, but the windings are distributed and connected in different ways, according to the kind of characteristic required.

STATOR. Fig. 9. Winding the stator of a B.T.-H. synchronous motor rated at 7,500 h.p., 93·8 r.p.m., for operation on 6,300 or 3,150 volts, at 50 cycles, to drive a rolling mill in India.

One of the stators of a frequency-changer is normally mounted so as to be rotatable through a small angle. The rotation is accomplished by a nut and spindle, operated by a hand-wheel, or distant controlled by a small motor. Slightly flexible main stator connexions are necessary, but the amount of movement required is only a fraction of a pole-pitch and does not involve very difficult arrangements. *See also under* Frequency Changers.

Motor stator frames must be provided with an earthing terminal, and a conductor of liberal section should be employed to connect with a low resistance earth, no reliance being placed upon incidental earthing through gears, bedplates, etc. Some engineers accept as an adequate earthing provision the bonding of the supply cable armouring to the stator through a proper grip fitting, or the use of flexible piping for the cables, which is bonded to an earthed conduit system.



STATOR. Fig. 10. Wound stator of a type "R" squirrel-cage induction motor.
The Metropolitan-Vickers Electrical Co., Ltd.

Thermo-electric couples (*q.v.*) are sometimes built into the slots of alternator stators, to indicate the actual temperature attained in this part of the machine, which is likely to be the hottest point. A much more accurate indication can be thus obtained than by the use of thermometers held against the core or windings. When thermometers are used while an A.C. machine is running, they should be of the spirit variety; a mercury thermometer may indicate inaccurately by reason of eddy currents induced in the mercury itself.

Faults and Failures. Stator faults are almost confined to failures of insulation of the windings and the repairs constitute work in the nature of Armature Winding (*q.v.*). Such faults are chiefly due, apart from manufacturing irregularities, to the effects of dampness upon the insulation. Dampness is an enemy of all electrical machinery which is not operated continuously and can be best met by the use of a totally enclosed machine. If a motor has been lying idle for some time and has become damp, this will be shown by a low insulation resistance test, and the windings must be dried out before the plant can be used. Drying out is best done in a proper vacuum oven. Generally it is only practicable to transport the motor to a convenient spot (*e.g.* the electrician's shop) and there pass low-tension current of full-load value through the windings for some hours, testing the insulation resistance from time to time, until a steady reasonable figure (in the order of $\frac{1}{2}$–1 megohm) is attained.

If the motor cannot be moved, the difficulty is to provide a suitable low-voltage current *in situ*, and various temporary expedients may be employed, the aim being by some means to raise the temperature of the windings to the highest figure which will be safe with the type of insulation in use.

Mechanical faults in electro-magnetic machines are associated with their rotors rather than their stators, but noisy running is sometimes caused by the vibration of stator core plates. The remedy is to make sure that the clamping bolts of the core, or those holding the reinforcing end plates on either side of

the core, are properly tight. When similar machines are being tested by the Hopkinson method of loading back, either the rotors or stators must be set at a small relative angle one to the other. If suitable couplings are not available, packing under the feet of the stators may be a convenient method.

STEATITE. A ceramic insulating material with great heat resistance properties, chiefly composed of magnesium silicate. Used extensively in place of porcelain insulators (*q.v.*) for overhead lines and similar purposes, especially under conditions where thermal insulation is essential.

STEEL: ITS CHARACTERISTICS, VARIETIES AND USES

Notes on the Varieties and Uses of Steels for Electrical Work

In addition to other metals described under the appropriate headings and under Alloys, reference should be made to those closely related to the present subject, e.g. Electro-Magnet; Iron; Iron Loss; Lifting Magnet; Permeability.

The addition to iron of a small quantity of carbon produces steel, which is used to a very great extent in all branches of engineering. Its strength and other characteristics can be varied within very wide limits to suit the use to which it is to be put. For instance, the steel employed for a rotor shaft is alloyed with small quantities of other metals, whereas that of the framework of a motor, in most cases, is ordinary tough, mild steel.

The hardness and strength of steel depend upon its carbon content and upon its heat treatment. In general, the higher the percentage of carbon the harder and stronger the steel, but it also becomes less tough and more brittle. Steel can only be hardened by heat treatment when it contains sufficient carbon.

Mild steel or low carbon steel contains in general less than about 0·25 per cent. of carbon, while hard or half-hard steel or high carbon steel contains a higher percentage, although there is no hard and fast distinction between the two. Only medium or high carbon steel can, however, be hardened and tempered.

Steel is frequently alloyed with small quantities of nickel, vanadium, chromium, manganese or molybdenum to obtain much greater strength and toughness.

Types of Steel. The variety of different steels is immense, and each specimen is capable of great variation in hardness and toughness, according to the heat treatment to which it is subjected. Wrought iron, which is mentioned for purposes of comparison, contains from 0·1 to 0·20 per cent. of carbon and is 99·5 per cent. pure. Its ultimate tensile strength is about 23 tons per square inch, and it cannot be hardened by heating and quenching.

Mild steel, as stated earlier, contains up to 0·25 per cent. of carbon, and is also non-hardening. Its tensile strength is, however, greater, being about 31 tons per square inch. It cannot be hardened and tempered, but it may be case-hardened.

Medium and high carbon steels contain up to 1·25 per cent. of carbon, but it must be clearly understood that all the varieties from wrought iron to high carbon steel shade off imperceptibly into one another. The strength depends upon the degree of hardening to which they are subjected, extremes of hardness and brittleness and of softness and toughness being attainable.

Alloy Steels. Further variations are possible with the alloy steels referred to above. Consider, for instance, a specimen of silicon-manganese steel, hardened and tempered so as to be suitable for valve springs. This steel contained 0·54 per cent. carbon, 1·95 silicon and 0·94 manganese. Its ultimate tensile strength was 91 tons per square inch. A second specimen of chrome-vanadium steel, hardened and tempered for the same purpose, contained 0·55 per cent. carbon, 0·29 silicon, 0·68 manganese, 0·10 nickel, 1·16 chromium and 0·27 vanadium. This steel had an ultimate tensile strength of 79 tons per square inch. These two specimens, however, possess a very valuable quality in that they do not suffer from what is known as fatigue. Some steels will fail by fatigue—that is, by frequent repetition of a load far below the normal breaking load—and the alloy steels are particularly valuable in meeting these special strains.

All varieties of steel possess one peculiarity which distinguishes them from both wrought and cast iron. They are cast and are afterwards rolled and hammered.

The figures of ultimate tensile strength of the different varieties of steel are given only as illustrations of the order of magnitude. There is great variation in strength, depending upon composition and heat treatment. The tensile and the crushing strengths are approximately the same in the tougher varieties, but in the harder steels the tensile strength, although greater than that of the softer steels, is much less than the crushing strength. As an example, bearing balls are made of an alloy steel which, when hardened, has a resistance to crushing of about 360 tons per square inch.

These alloys are very simply produced in the electric furnace, the oxide of the metal and carbon being added to the iron in order to produce the desired ferro-alloy.

Magnetic Steel. Iron, steel, nickel and cobalt are the best conductors of magnetic lines of force, but for magnetic circuits in practical machines iron and steel alone are used, being cheaper and more easily worked than the two latter metals.

It is stated under Iron (*q.v.*) that all substances mixed or alloyed with iron lower the permeability. In steel the decrease in permeability is proportional to the amount of carbon present, whilst aluminium, silicon and other substances which give softness and homogeneity to the metal increase the permeability when present in limited quantities.

Cast steel can be worked economically at a flux density of 15,000 lines per square cm., compared to the economical limit of 7,000 lines per square cm. for cast iron, and is therefore adopted for magnet frames when weight is an important consideration, as in traction motors. More usually, laminated steel pole pieces are bolted on to the cast-iron magnet frames, resulting in considerable reduction in the weight of copper in the field coils.

Strong permanent magnets can also be made of steel, this being one of the main differences between it and wrought iron, which is almost useless for such purposes. Recent development of new nickel-aluminium magnet steel may have far-reaching effects on the magnet industry.

Non-magnetic Steel. The addition of manganese in certain proportions to good magnetic steel results in a non-magnetic alloy. Thus a sample of steel containing 15 per cent. of manganese has a magnetic moment of less than 1-7,000th of that of a similar piece of good magnetic steel. Similarly, a nickel-steel alloy, both of whose constituents are magnetic, results in a substance nearly non-magnetic. A nickel-steel containing 25 per cent. of nickel has been observed to have a permeability of 1·4, whether the field in which it is placed be strong or weak.

These non-magnetic properties prove advantageous in the construction of certain forms of apparatus and machines. The phenomena are very complex, however. In the case of the steel just referred to, Hopkinson found that it became magnetic when cooled below 0°C. Further, it retained this property when heated up again to 580° C., when it again became non-magnetic, and remained so when cooled to ordinary temperatures. Important researches on these lines continue.

Non-ageing Steel. As has been previously remarked, steel with high retentivity and high coercivity is adopted for permanent magnets. These properties are imparted by the addition of small quantities of chromium, tungsten and molybdenum to iron. The "ageing" of such magnets is accomplished by tempering glass-hard, steam annealing for 30 hours and magnetizing to saturation. This enables the ageing effect, which causes increase in hysteresis loss of transformer cores after a long period of use, to be effected in a short time, and steel which has been so treated will not deteriorate further in magnetic properties.

Heat-resisting Steel. Most metals are incapable of resisting chemical attack at high temperatures, and tend to lose rigidity resulting in a slow, continuous alteration of shape under the weight of the metal itself (known as creep). Cast iron is mechanically weak and scales rapidly, whilst ceramic materials have only a limited application due to their fragility. Special heat-resisting steels have therefore been developed capable of resisting corrosion and distortion for considerable periods at temperatures of more than 1,000° C. These steels contain

a considerable proportion of chromium, up to 30 per cent. being added where extreme resistance to high temperatures is required.

The addition of nickel and small quantities of other special elements affords extra resistance to stress in chrome-steel. Such steels are extensively employed for mechanical furnace rabbles and stokers, conveyers working in furnace interiors and similar applications; whilst high nickel-steel with addition of chromium is employed for turbine blading, being unaffected by steam during long service.

Steel Progress in the Electrical Industry. The following notes from an article in "The Electrical Review" of October 27th, 1933, indicate recent important advances in steel developments:

Hitherto in the manufacture of electrical switchgear it has usually been found impossible to employ steel castings for some of the smaller parts, owing to the difficulty of obtaining them true to shape and size and free from defects. This difficulty has now been overcome by the use of a new method for the manufacture of very light and intricate steel castings in the Sheffield steel foundry industry. These are so true to form that jigs can be employed in their manufacture during production. The method itself is to some extent a trade secret, but a special method of coring is the principal factor.

Marked advances have been made in the manufacture of stainless steel castings. Until recently the steel castings obtainable—at all events those of small size—were unsatisfactory in the majority of cases owing to roughness of surface, leading to eventual corrosion; distortion of shape; and inaccurate dimensions. These troubles have largely been overcome, and small stainless steel castings can now be obtained with excellent surface, satisfactory shape, and freedom from pitting. Such parts as fittings, handrails, taps, cocks, door-handles, valves, and the like can all be made now in the form of stainless steel castings.

Plated Rubber Moulds. The demands of the rubber industry have led to a valuable advance in connexion with moulds for the manufacture of rubber articles. This is the chromium plating of steel moulds. In the past it has been the practice to manufacture these of a good quality alloy steel. The new method is to copper plate first, then chromium plate, the moulds, as a result of which they receive the essential hardness and smoothness of surface. With this double plating it is no longer necessary to employ steels of so high a quality. The cost of the two plating operations is less than the total saving on steel, so that the method has the advantage of cheapness. Nevertheless, before this process is universally adopted, certain disadvantages, such as the flaking off of the plating, will need to be completely overcome. The results so far obtained have been extremely encouraging.

Nitriding. A new development of great value is the nitriding process, which is a means of obtaining an extremely hard and durable surface on steels not in themselves hard, leaving a core of soft material within. Nitriding is thus, in essentials, a case-hardening process, but the difference is that whereas in the latter carbon is the hardening agent, in nitriding it is nitrogen which penetrates the skin of the steel and ensures hardness; the result is obtained by heating the parts in ammonia, which gives a harder surface, and no later heat-treatment of any parts nitrided is necessary, so that they can be put straight into use, whereas, with case-hardening, heat-treatment is essential after the hardening. Thus, finished machined parts can be nitrided without losing shape.

The enormous increase in the use of synthetic materials from which objects and parts are moulded or pressed has caused a correspondingly important advance in steels for press tools, punches, dies, etc., for working these materials. Three principal steels have been evolved for this work, the first being a tungsten-chrome-manganese steel, high in carbon, and containing in addition a small percentage of silicon. The second is a chrome-silicon-manganese steel, with sometimes a little molybdenum added. The third is a cobalt-silicon-molybdenum steel, with high carbon content and a small proportion of manganese. The first of these is a standard steel, oil-hardening, and easy to heat-treat; it is used where low price, or the fact that the materials to be worked or the operations to be performed are not

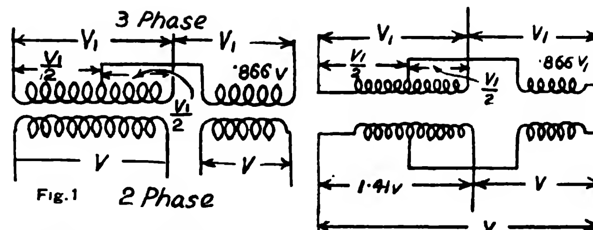
heavy in their demands, is the main consideration. The second steel is more expensive, hardens in air, needs careful heat-treatment, but more than repays its cost in the fact that it will stand up admirably to extra-long runs and very hard service. The third steel is also air-hardening, offers extraordinary resistance to wear, and is extremely hard. It is best adapted for cold pressing.

Fusion-welded Tools. Turning to cutting steels, there have been no sensational changes in base material, the cobalt high-speed steels continuing to reign supreme; but the fusion-welding process has been a revolutionary development. By the employment of a special electric fusion-welding technique, it has become possible to weld small ends of super-high-speed steel on to high-grade steel shanks, forming as a result cutting tools ready for use; these can be sold at a price so low that they can be afforded by even the smallest user. They do all the work of a solid high-speed-steel tool at a much lower cost, and the low price enables the user to scrap them ruthlessly when the end is used up and buy more.

The welded part of these tools is a solid *end*, and the tools will fracture anywhere but at the point of union.

A file for bakelite and similar materials is another recent development. Usually the trouble in filing bakelite, vulcanite, etc., is due to the clogging of the teeth of the file, which reduces the tool's effectiveness and makes filing harder and slower. The improved file has teeth cut like the arc of a circle, angle and shape being carefully planned to give the greatest cutting power combined with speedy freeing of the teeth from adherent particles. A good quality high carbon steel is employed, and files up to 14 in. can be obtained.

STEINMETZ COEFFICIENT. According to his law for calculation of hysteresis losses in magnetic materials, Steinmetz stated that ergs loss per cycle per c.c. were $\mu B^{1.6}$ where μ is a coefficient depending upon the material used. For iron μ is 0·00 to 0·003, for annealed steel 0·008, and hardened steel 0·025. Sometimes this coefficient is represented by *h*.



STEINMETZ CONNEXION. Fig. 1. The Scott method of connexion. Fig. 2. Steinmetz connexions of primaries and secondaries for three-phase to two-phase conversion. See also page 1059.

STEINMETZ CONNEXION. A similar method of transformer connexion to the Scott connexion (*q.v.*), but with the secondaries connected similarly to the primaries. One secondary is tapped at its mid point and connected to the other secondary just as in the case of the primaries, the second secondary having ·866 times as many turns as the first. A two-phase supply is obtained across the two outers and across the two remaining secondary terminals as shown in the diagram.

STEP WINDING. To overcome the disadvantages of starting, induction motors (*q.v.*) have been designed with two windings whose characteristics can be varied within wide limits enabling high starting torque to be attained. In addition to the normal low-resistance squirrel-cage winding, a high-resistance low-inductance starting winding is incorporated on the rotor. A short-circuiting device enables the latter winding to be cut out entirely on reaching running speed, the whole construction being referred to as a step winding. *See* Starters.

STOBIE FURNACE. A type of arc furnace in which special attention has been paid to mechanical design and incorporating specially robust electrode gear. Hearth electrodes are employed in the smaller sizes and top electrodes in the larger, with a pair to each phase, permitting higher voltage and improved power factor to be maintained. An average energy consumption for this type of furnace is about 600 B.Th.U. per ton of steel. *See* Arc Furnace; Furnace.

STOP AND START SWITCH. Relay-actuating switches, usually of the push-button type (*q.v.*), which set in motion a

series of mechanisms culminating in the stopping or starting of the apparatus under control. Extensively employed in automatic substations, lift control, emergency switches, wireless telegraphy, automatic telephony and many other similar applications. The closing of the switch completes the relay circuit, thereby closing the main operating circuit which controls and carries out the desired sequence of operations.

STORAGE BATTERY AND STORAGE CELL. A battery or cell which has to undergo chemical change before it can deliver electrical energy in a discharge circuit. The chemical change is produced by charging (*q.v.*) and such a system is an accumulator or secondary battery.

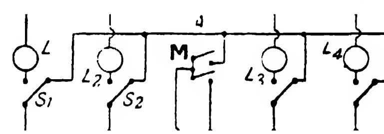
The types of storage batteries in wide use are lead-acid, Edison and Jungner; the latter, like the Edison cell, being alkaline, but with a negative element consisting of an iron and cadmium mixture that gives some more favourable characteristics than those possessed by the Edison cell. *See* Accumulator; Active Material; Battery; Edison Accumulator; Sulphating.

STORAGE SYSTEM. *See* Thermal Storage System.

STRANDED CONDUCTORS. According to the I.E.E. regulations for the electrical equipment of buildings, the maximum size of a single wire must not exceed 0·003 sq. in. All conductors having a nominal sectional area exceeding 0·003 sq. in. (1/·064 in.) must therefore be stranded. The definition of a stranded conductor, according to B.S.S. No. 7, 1926, is a conductor consisting of three or more circular wires laid up or twisted together to form one conductor. This construction gives greater flexibility and strength to the conductor, and yields a lower resistance to very high frequency currents due to skin effect (*q.v.*). In cases where great strength is required, as in overhead lines, the conductive material is laid up in strands round a steel core (formerly a hemp core was employed). Armature conductors are also often stranded to improve their flexibility and minimize eddy currents.

An increase of 2 per cent. in the length of each wire, except the centre wire, in a stranded conductor is assumed to allow for the laying up of the wires, and the resistance is calculated upon the assumption that the individual wires are practically insulated from each other, whilst the area of the stranded conductor is taken to be the area of the solid wire which has the same resistance as the stranded conductor. The sizes, weights and resistances of standard solid and stranded circular conductors are given in the table in page 327. *See* Aluminium; Cable; Conductor; Copper, *etc.*

STRAPPING WIRES. When a number of lamps and their two-way switches are to be wired up to a master control switch, strapping wires are used to interconnect the switches. The master switch can then be connected at any point in the strapping



STRAPPING WIRES. A and B, strapping wires; L_1, L_2, L_3, L_4, lamps; S_1, S_2, S_3, S_4, two-way switches; M, the master switch.

wires, which are not directly connected to either the leads or the lamps themselves, but merely strap together the switches. Their function will be more clearly understood by reference to the diagram. in which the two-pole master switch M controls all the two-way switches S_1, S_2, and S_3 and their connected lamps L_1, L_2, and L_3. When M is open, all the switches are dead and the lights extinguished. If either half of M be on, the lamps may be controlled by their respective two-way switches, but if both halves are on all the lamps will be lit and cannot be switched off by manipulating the two-way switches. Such an arrangement is of use where corridor lights are to be switched off by the housekeeper in flats, hotels, offices, etc., at a certain hour. A disadvantage lies in the fact that on switching on again any lamps which had formerly been in circuit would be relit and require switching off at their respective two-way switches. *See* Marvel Switch; Two-way Switch; Wiring, *etc.*

STRAY CURRENTS. Currents which flow in systems through small out-of-balance effects that cannot be entirely

corrected in practice. An instance of these currents is found in the split conductor method of circuit protection. Variations in the characteristics of the two transformers cause so-called stray currents to flow in protective relays. The term, therefore, refers to currents due to out-of-balance or unsatisfactorily balanced E.M.F.'s. *See* Protective Devices; Split Conductor System; Transient Currents.

STREET LIGHTING AND THE NEW DEVELOPMENTS

By L. J. Luffingham

While, as stated below, about half the roads of the country are lighted by electricity, there is little doubt that the development of hot cathode lamps will probably result in its exclusive use in a relatively few years. The standards and systems now in use are given, together with notes on the newer methods, their great superiority being demonstrated by photographs given in a special plate. See Floodlighting; Gaseous Discharge Tubes; Hot Cathode Lamp.

The responsibility of street lighting rests with the local authorities, which is the main reason for the wide divergences in the quality of illumination provided in different areas, and in London even in the same street. Where a borough boundary passes down the middle of a street it is not uncommon to find good lighting on one side and bad lighting on the other. The importance of good street lighting from the standpoints of safety and general amenities, and the low standard in general at present prevailing, is such that the future will probably see street lighting raised to the status of a national service under direct central government control.

At the present time roughly 50 per cent. of the street lighting in the country is done by electricity and the other half by gas. Electricity is steadily superseding gas at a rate that should result in all-electric street lighting in about 20 years. That period may be considerably shortened by the advent of the new highly efficient gaseous discharge lamp (*q.v.*), and intensive educational propaganda by electrical interests. In the main, the more important thoroughfares in most big towns are comparatively well lighted. Illumination of secondary and side streets is, however, far less satisfactory, and such streets by their great numerical superiority constitute the major part of the street lighting problem and the biggest scope for improvement.

Street Lighting Standards. The desirable standards of street lighting illumination are set out in detail in B.S.S. No. 307–1931. Therein are specified eight classes of installation, graded according to minimum illumination intensity provided, and for each class recommendations as to the height of light sources above the ground, spacing-height ratios, etc., are given. These specification data are given in the summarized table.

STREET LIGHTING RECOMMENDATIONS OF B.S.S. 307–1931

Class of Street This classification is not included in the Specification proper	Classification		Height of Light Source Above Ground		Maximum Spacing Height Ratio	
		Min. Rated Mean Test Point Illumination of Roadway	Min	Lowest Recommended	Max.	Recommended Not more than
Spectacular lighting	A	2·0 ft. C. and upwards	30 ft.	30 ft.	5	3
Important thoroughfares, etc.	B	1·0 ,,	25 ,,	27½ ,,	6	4
Main commercial thoroughfares	C	0·5 ,,	21 ,,	25 ,,	8	5
Lesser important com. thorfs.	D	0·2 ,,	18 ,,	21 ,,	9	6
Shopping areas, provincial ..	E	0·1 ,,	15 ,,	18 ,,	10	7
Main suburban roads	F	0·05 ,,	13 ,,	15 ,,	12	8
Residential streets	G	0·02 ,,	13 ,,	13 ,,	12	10
Poorest lit roads	H	0·01 ,,	13 ,,	13 ,,	12	10

The "class of street" description is not contained in the specification, but is given as a rough general guide. Within what illumination class any particular street or centre should come is mainly to be determined by local conditions; the principal street in a small provincial town would not require such a high standard of lighting as a corresponding street in a big city, and so on.

Class A may be regarded as setting the

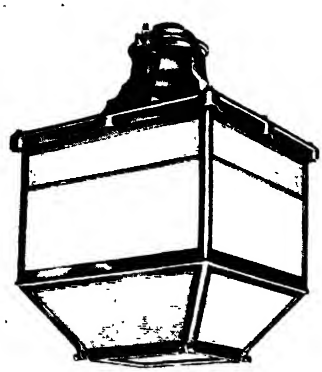


Fig. 1a

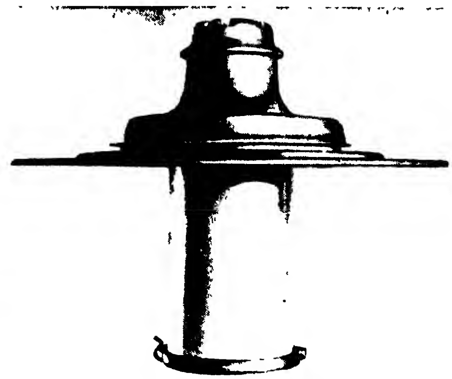


Fig. 2a

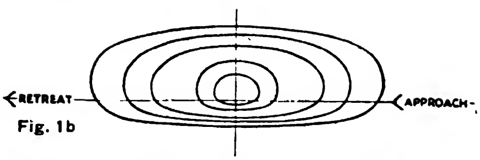


Fig. 1b

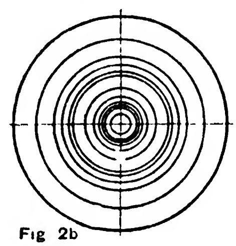


Fig 2b

STREET LIGHTING. Fig. 1a (top of page). The Diron street lantern. Fig. 1b. Polar curve for Fig. 1a. Fig. 2a. The Circra lantern. Fig. 2b (right). Polar curve for Fig. 2a.

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all other relevant information.

Systems of Street Lighting. There are two main systems of lighting; (a) by light sources staggered alternately on either side of the road, and (b) central suspension in which the lamps are hung over the centre of the roadway. Each has advantages for different conditions. The staggered arrangement is the more common and satisfactory in general use. Where, however, there are trees lining the streets, or other obstructions that would interfere with the efficient light distribution, central suspension is to be preferred. Again, in narrow thoroughfares, suspending the light sources on span wires stretched between the buildings relieves the roadway of all obstruction.

The choice of system in any particular installation is very largely determined by local conditions favouring economically one or the other. It is sometimes claimed for the central suspension system that it gives more efficient lighting, but when assessing that claim care must be taken to observe that better lighting on the roadway has not been secured by sacrificing

ideal standard, and Class H the irreducible minimum, not always reached even yet.

In addition to the above data the specification lays down that the rated mean test-point illumination of the footway shall not be less than 0·4 times that of the rated mean test-point illumination of the roadway, and shall not fall below the value 0·2 in service. The general requirement for service maintenance is that the actual illumination shall not be allowed at any time to drop below one half the illumination values obtained on test, both for carriage and footway. Full particulars are given in the specification as to the positions and conditions for taking tests with the various systems of lighting, and

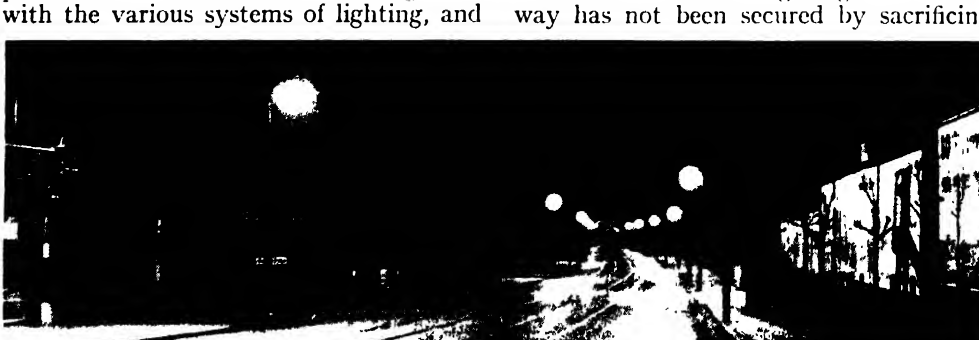

Fig. 3. A section of the Romford Road, London, lighted by lanterns as shown in Fig. 1a.

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STREET LIGHTING. Fig. 4b. Polar curve of (a) 400 and (b) 500 watt Osira lamps. Fig. 4c. Wiring diagram for street lighting by the lamp shown in Fig. 4a. below.

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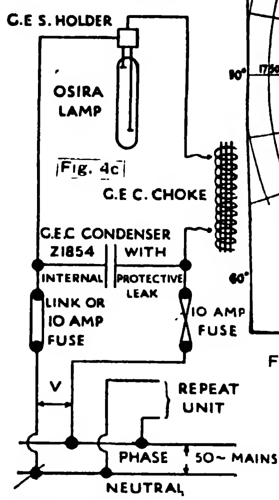


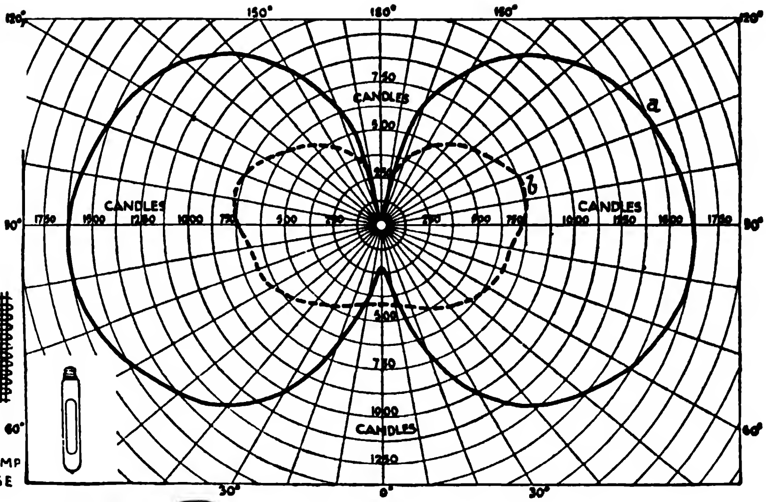


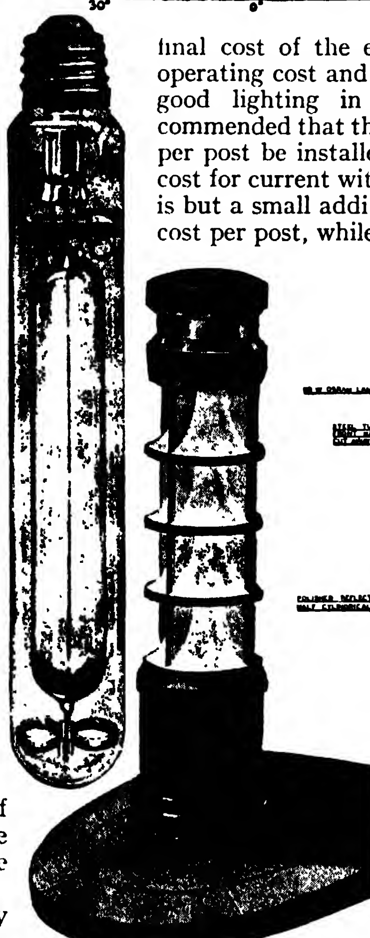
Fig. 4b

Fig. 4a. The G.E.C. Osira lamp whose polar curve appears in Fig. 4b.

illumination on the footways and buildings flanking the road. With both systems it is most important that glare be avoided. This is best secured by adequate supporting height in relation to the intensity of the light source.

Light Sources. Until the recent advent of gaseous discharge lamps, ordinary metal filament lamps were used almost exclusively for electric street lighting. They had virtually superseded arc lamps, of which there are nowadays comparatively few installations remaining as relics of the past. Metal filament lamps are used in all standard sizes from 40 to 1,500 watts. From the standpoint of light efficiency the larger the lamp used in the light source the better.

But the final choice in any installation is, of course, influenced by many other factors—standard of lighting required, final cost of the equipment as a whole, operating cost and maintenance, etc. For good lighting in urban areas it is recommended that the minimum of 100 watt per post be installed. Note the increased cost for current with higher wattage lamps is but a small addition to the total annual cost per post, while a proportionally much



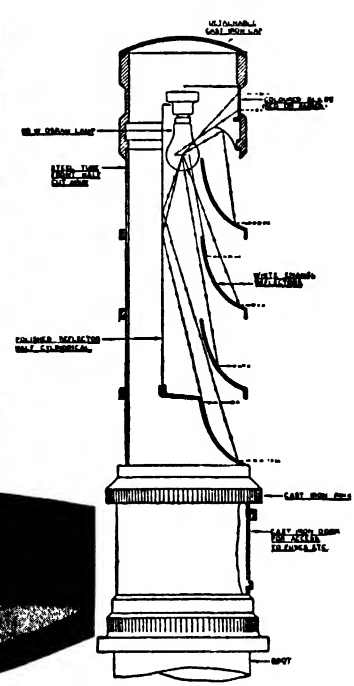


Fig. 5 (left), A luminous refuge bollard : (right), schematic arrangement of this bollard.

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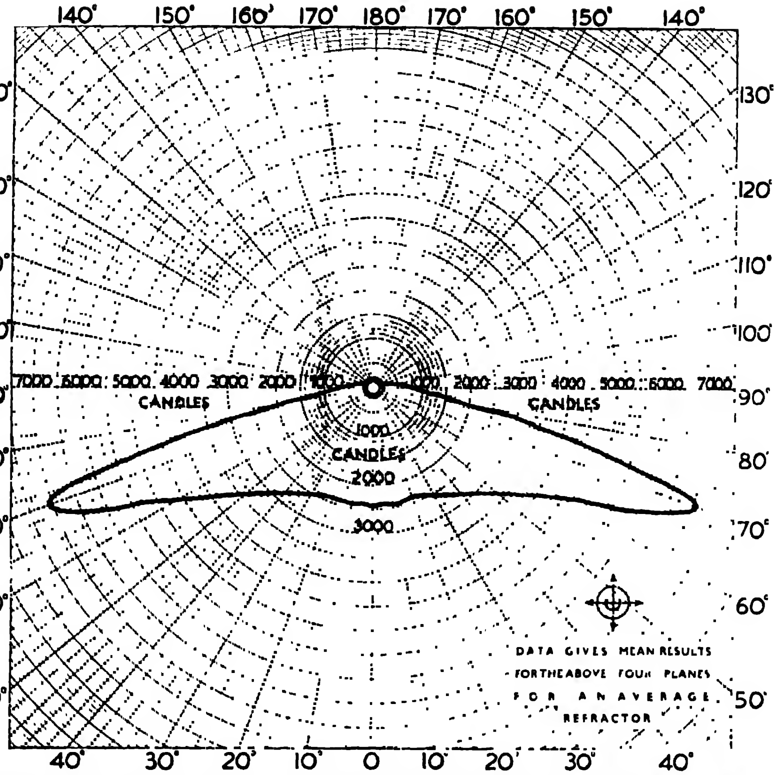


STREET LIGHTING. Fig 6a (below). The G.E.C. Wembley type lantern for 300 or 500 watt lamps shown in Fig. 4a. Fig. 6b (above). Polar curve for the lantern, Fig. 6a.
General Electric Co., Ltd., of England

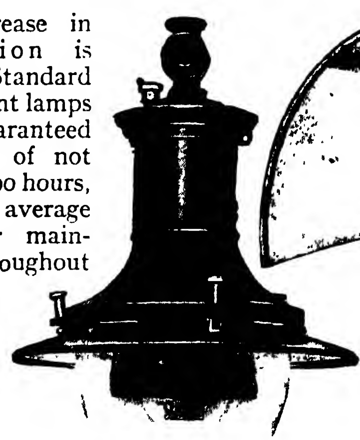


Fig. 6a

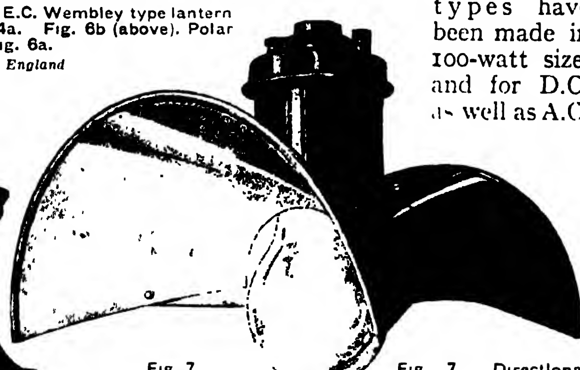
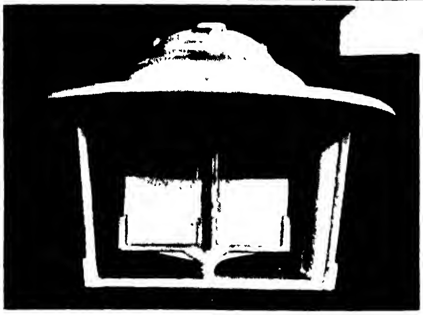


Fig 7

Fig. 7. Directional reflector fitting having detachable dome to facilitate wiring, and an externally operated lamp focussing device.
Revo Electric Co., Ltd.

greater increase in illumination is obtained. Standard metal filament lamps have a guaranteed average life of not less than 1,000 hours, and the average candle-power maintenance throughout this life is 93 to 95 per cent. The gaseous discharge lamp has introduced a revolutionary factor into street lighting practice, the effect of which must be increasingly felt in the future. Such lamps give from two to three times the light output of gasfilled filament lamps, and the cylindrical light source, giving a very much larger luminous area than that of a metal filament, contributes substantially to the reduction of glare. Technical problems associated with the utilization of gaseous discharge lamps have been satisfactorily overcome, and already a large number of installations are in existence. In general the light sources are 400 watts, but certain types have been made in 100-watt size, and for D.C. as well as A.C.

The principal criticism is the deficiency of red rays in the light emitted, which gives false colour values to objects illuminated. While this disadvantage has not been completely overcome it has been to a degree sufficient to be satisfactory for street lighting purposes. The combination of a gaseous discharge lamp with metal filament lamps in the same lantern, or



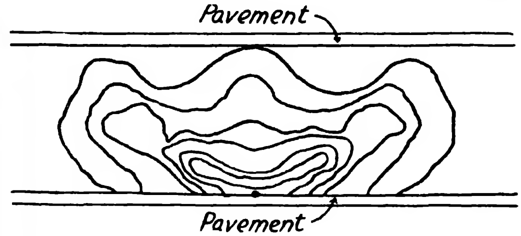


Fig. 8 (left) Interior of a street lantern using gaseous discharge lamps Fig 9 (above). The iso-candle polar curve of this lantern as actually installed in the street shown in Fig 12 below

Fig. 10 (right). Schematic lay-out of the lanterns shown in Fig 8 as they are installed in Fig. 12. Method of connexion to the supply mains is indicated, together with the street width and lantern spacing along the road The high efficiency of these lanterns allows considerable economy to be effected in the number of lighting points

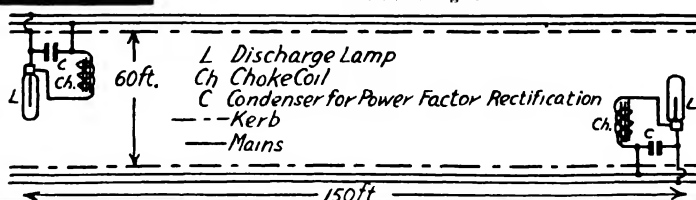


Fig. 11 (upper). View of Wadham Road, Walthamstow, illuminated by ordinary gas-filled electric lamps. Fig 12 (below). The same street from the same point of view showing the improved effects of installing the lanterns shown above with Sieray colour-corrected lamps.

STREET LIGHTING: THE MODERN ANSWER TO A PRACTICAL PROBLEM

Photographs and diagrams by courtesy of Siemens Electric Lamps & Supplies, Ltd

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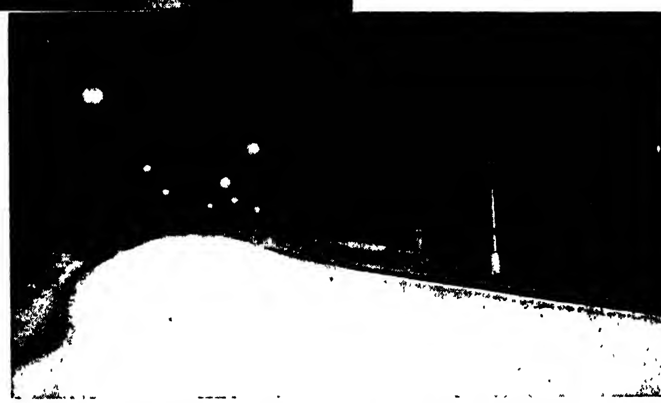


STREET LIGHTING. Fig. 13a (above). Stratford Road, Birmingham, lighted by gas. Fig. 13b (below). The same street after conversion to gaseous discharge lanterns.
General Electric Co., Ltd., of England.

light source, gives very nearly true colour values, and, while not overall so efficient as the gaseous lamps alone would be, is still a marked advance on metal filament lamps alone.

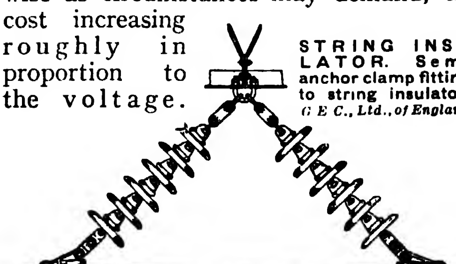
To conform with the nature of this new light source new styles and designs of lanterns have been evolved. As regards life and candle-power maintenance the gaseous lamp promises to be as good or better than the metal filament type. The development of a new light source two to three times as efficient as existing sources can be utilized in two ways. It can be applied to give existing illumination values at lower operating cost, or higher illumination standards without increase of operating cost. The latter is obviously the better. Details of theory and construction of these lamps are given under Gaseous Discharge Lamp, and Hot Cathode Lamp.

Planning a Street Lighting Installation. The class of lighting has first to be decided upon. Then, based on the width of the roadway, tables are consulted to ascertain the maximum spacing of light sources with corresponding mounting height to comply with B.S.S. 307. A sketch plan can then be prepared, the positions of the light sources being marked. From this the test point positions, as defined in the specification, are determined. The minimum light intensity to be made available at these points is, again, ascertained from the tables. Then from the polar diagrams of the fittings being adopted where these are symmetrical, or isocandle diagrams for asymmetrical fittings, the necessary candle-power is determined. The important point that this brief outline of planning a street lighting installation emphasizes is the exactitude with which any desired standard of illumination can be designed for, with the certainty that it will be realized by the installation when finally carried out.

STRESS, DIELECTRIC OR ELECTROSTATIC. *See* Dielectric; Puncture Strength.

STRING GALVANOMETER. *See* Einthoven Galvanometer.

STRING INSULATOR. A number of suspension type insulators (*q.v.*) arranged in series may be referred to as a string insulator. This is an economical construction capable of extension or otherwise as circumstances may demand, the cost increasing roughly in proportion to the voltage.



STRING INSULATOR. Semi-anchor clamp fittings to string insulators.
G. E. C., Ltd., of England.

The pressure is not equally distributed over identical insulators constituting a string, due to earth capacity effects, and close-coupling of the units with guard-ring protection against arcing is desirable. *See* Suspension-type Insulator.

STROBOSCOPIC TEST. A test for the synchronization of a rotating mechanism, by visual indication. In one form of stroboscope a 3-inch disc is used marked in alternate black and white portions and illuminated by a neon tube operating at the same frequency as the apparatus in question. The disc is fitted to the revolving mechanism, and since the light pulsates in accordance with the fluctuations in current, for synchronism the whirling disc appears to be stationary, due to the relationship between the speed of the light fluctuations and the size of the disc divisions and its speed. Such stroboscopes are used in recording apparatus and sound film work, whilst the photometer disc described under Illumination (*q.v.*) makes use of the same principle.

SUB-CIRCUIT. A sub-circuit is defined as a branch circuit connected to a distribution board or fuse-board fed from a main circuit. The I.E.E. regulations (1934 edition) for the electrical equipment of buildings (*q.v.*) lay down certain requirements in regard to the arrangement of final sub-circuits as follows:—

Final Sub-Circuits.—201 (A). Every final sub-circuit shall be connected to a separate way on a distribution fuse-board, except that where there is only one final sub-circuit it may be directly connected to the main switchgear.

Above 15 *amps.*- (B). A final sub-circuit having a rated capacity exceeding 15 ampères shall not supply more than one point.

Up to 15 *amps.*—(C). A final sub-circuit having a rated capacity not exceeding 15 ampères may supply any number of points up to 10, and in such sub-circuit the size of every cable (including flexible cord), lampholder, and socket-outlet, in relation to the current rating of the fuse-link (or to the adjustment of the circuit breaker) protecting the sub-circuit, shall be in accordance with the requirements of the schedule below.

Grouped Lampholders.— (D). In cornice lighting, panel lighting, and electric signs, where lampholders are grouped in close proximity to each other and are connected to the circuit without flexible cords each lampholder shall not, for the purposes of clauses (B) and (C) above, be considered to be one point. In these circumstances more than 10 lampholders may be connected to a final sub-circuit, provided that the maximum working current in such sub-circuit does not exceed 10 ampères, and also provided that any such electric sign is controlled by a cut-out on each pole and a multi-pole (linked) switch, or by a multi-pole (linked) circuit breaker, subject to the observance of Regulations 112 to 114 inclusive and Regulation 1204.

Circuit Feeding Socket-outlets.—(E). A final sub-circuit supplying current to one or more 5-ampère socket-outlets, or to a 15-ampère socket-outlet, shall have its conductors of such cross-sectional area as will permit of their carrying the total current corresponding to the sum of the ratings of every socket-outlet connected to such circuit.

2-amp. Socket-outlets. — (F) A 2-ampère socket-outlet intended for lighting only may, for the purposes of clauses (B), (C), and (E) above, be deemed to be a point supplying one lamp.

(G). Sub-circuit cut-outs mounted in accordance with Regulation 614 shall be provided for the protection of final sub-circuits supplying socket-outlets, irrespective of the use therewith of plugs or socket-outlet adaptors containing cut-outs.

Fittings Wire.—(H). Fittings wire shall be used only for the internal wiring of fittings.

Sizes of Flexible Conductors.—(I). In the event of the readjustment of a circuit breaker or the replacement of a fuse-link protecting a final sub-circuit by a fuse-link of larger rating, every flexible conductor connected to the sub-circuit shall be increased in size, where necessary, in order to conform with columns 1, 2, and 6 of the schedule referred to in clause (C) above.

Size of Lampholders.— (J). The size of every lampholder fitted on a final sub-circuit shall depend on the current rating of the fuse-link, or the adjustment of the circuit breaker, protecting the circuit.

1 - Where a final sub-circuit is protected by a circuit breaker or fuse-link adjusted or rated in accordance with column 1 or column 2 respectively, then the smallest cables and flexible cords that may be used in any part of such sub-circuit without further protection [see Regulations 202, 203, 607 (1), and 1331] are shown in columns 4 to 6

Circuit Breaker or Fuse-Link			Minimum Size of Cable other than Flexible Cord		Minimum Size of Flexible Cord
Adjustment of Circuit Breaker	Current Rating of Fuse-Link	Size of Fuse Wire (Tinned Copper)	Nominal Cross-Sectional Area of Conductor	Number and Diameter (in.) of Wires	Number and Diameter (in.) of Wires
1	2	3	4	5	6
amps.	amps	S W G	Sq in		
Up to 4	3	38	0·0015	1/·044	14/·0076
4·1 „ 6	—	—	0·0015	1/·044	23/·0076
6·1 „ 10	5	35	0·0015	1/·044	40/·0076
10·1 „ 20	10	29	0·003	3/·036	70/·0076
20·1 „ 30	15	25	0·0045	7/·029	110/·0076

SUB-STANDARD. A grade of accuracy for instruments adopted by the B.S.I. as discussed under the heading Instruments. *See also* Wattmeter.

SUB-STATIONS: MANUAL AND AUTOMATIC

By C. C. Garrard, Ph.D., M.I.E.E., A.Am.I.E.E., and C. J. O. Garrard, M.Sc.

This article first discusses the construction and lay-out of indoor and outdoor manual sub-stations for interconnexion and distribution, with a special note on "Grid" sub-stations. Next a description is given of the operation and functioning of completely automatic sub-station apparatus, concluding with a section on supervisory control. **See Converter; Mercury Arc Rectifier; Power Station; Remote Control; Switchgear; Transformer, etc.**

A sub-station is defined by the B.S.I. Glossary of Terms used in Electrical Engineering as "an assemblage of equipment installed for the supply of electrical energy and comprising converting or transforming machinery, batteries or controlling apparatus but no prime movers." The term includes indoor and outdoor sub-stations from the simple pole-mounted distribution transformer sub-station of a few kVA capacity to the large indoor rotary converter sub-stations for electric traction and the still larger outdoor transformer and switching sub-stations such as are used on the national "Grid" system.

Sub-stations may be classified according to their object into:

1. Interconnexion sub-stations, such as those of the "Grid," which are used for connecting together different sections of a transmission system or linking separate transmission systems. Such stations may on occasion have no transforming machinery at all, but only switchgear.

2. Distribution sub-stations, which are used to supply a low-tension network from a high-tension system, and convert the electrical energy into a form suitable for consumption.

A subdivision is also possible according to the type of machinery used, transformers, rotary-converters, rectifiers, etc.

3. Synchronous condenser stations which supply only the reactive power required to preserve the stability and regulation of long transmission lines.

A second classification is possible according to the type of enclosure used, into: 1. Indoor sub-stations; 2. Underground sub-stations; 3. Outdoor sub-stations; 4. Kiosk sub-stations.

Finally, they may be distinguished according to the type of control, whether manual, automatic, or supervisory.

Indoor Sub-Stations. Rotating machinery demands adequate protection from the weather both for itself and for the persons who have to look after it. For this reason indoor sub-stations are almost invariably used when the converting machinery consists of rotaries, motor-converters, and so on. In America several synchronous condensers have been installed in the open air; they are, however, completely enclosed in an air-tight shell and use hydrogen for cooling instead of air.

Where space is limited two- or three-storey buildings may be used, the heavy machinery and transformers being on the ground floor and the switchgear above. It is thus possible to achieve a desirable result, namely, the isolation of different pieces of apparatus from one another. If all the apparatus is on the ground floor it may be lodged in a number of separate compartments.

The ventilation of sub-stations is very important. The losses of the machinery appear as hot air, which must be evacuated. In addition, care must be taken that, with changes of temperature and humidity in the atmosphere, undue condensation does not take place in the station. To assure this, artificial ventilation and heating are occasionally necessary.

Buildings must be made as fireproof as possible, particular attention being paid to rapid and safe drainage of oil, which may leak as the result of damage to transformer and circuit-breaker tanks.

Underground Sub-Stations. These are used exclusively in urban areas where it is impossible to obtain sites for ordinary stations, and their construction presents many problems. Except in the case of underground traction sub-stations, the apparatus is usually confined to transformers and switchgear. Particular attention must be paid to the question of flooding and adequate ventilation be provided. Wherever possible the chambers containing the apparatus should be above sewer level so that drains can be installed;

SUB-STATION. Fig. 1. One of a group of high-speed circuit breakers used to protect the feeders of a sub-station.

General Electric Co., Ltd., of England.

where this is not possible it is frequently necessary to arrange a sump into which any water that enters the chamber can flow, and empty this periodically by means of a portable pump or automatically by a float-operated pump.

Ventilation can be by means of a chimney opening some distance above pavement level, the hot air being relied upon for inducing a draught.

Kiosks. For small installations sheet steel kiosks are economical, convenient and occupy a relatively small space. In these the transformer, H.T. switchgear and L.T. distribution gear occupy separate compartments, and the whole assembly possesses a high degree of safety to the operator.

Outdoor Sub-Stations. For extra high voltages, where large clearances between phases and to earth are necessary, outdoor sub-stations are very attractive, both on account of cheapness and ease of installation. They are also used for rural distribution systems where the reduction of cost is all-important.

Open-type gear is most generally employed, although of late outdoor type metal-clad switchgear has come more and more into favour, particularly on the lower-voltage sections of the "Grid." (For a description of such apparatus *see* Switchgear.)

As is the case with underground sub-stations, the apparatus in outdoor stations is usually confined to transformers and switchgear; the general principles governing the lay-out of such apparatus are dealt with under the heading Switchgear.

Outdoor sub-stations may be classified conveniently, according to the arrangement of the supporting structure, into high, medium and low types.

The high type is used principally for large sub-stations and where space is scarce, as the use of either of the other types would lead to the superficial area of the station being excessive. The transformers and oil circuit breakers are mounted on the ground, with the isolating switches above and the bus-bars above these (Fig. 10). This construction has the disadvantage of being expensive, both on account of the supporting structure and of the operating gear for the isolating switches.

In the medium type of station (Fig. 7) circuit breakers and isolating switches are mounted at about the same height, the latter being supported on frameworks about 6 ft.–7 ft. high, and the bus-bars are above the isolating switches. This has the advantage of giving a very simple arrangement and one that is easy to follow.

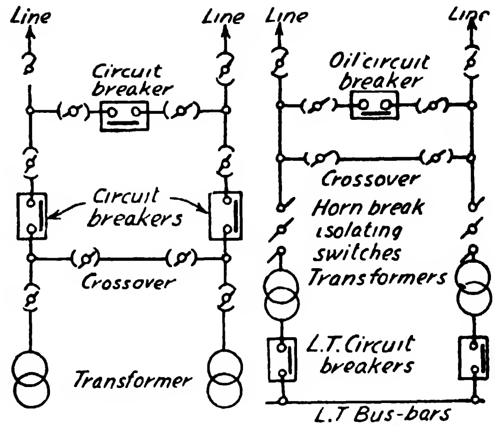
In the low type, bus-bars, isolating switches and oil switches are all more or less at the same height. This arrangement effects the maximum economy of supporting structure, but requires much space. The conductors must be at such a distance from the ground that it is possible to walk underneath them in safety, even after a heavy fall of snow.

For high structures lattice masts and girders are commonly used, although from many points of view they could advantageously be replaced by girders built up of plates and rolled sections; lattice structures are relatively expensive to paint and being somewhat bulky are liable to confuse the view of the apparatus mounted on them. They are, however,

light and cheap. Solid girders give a neater appearance and are easily painted. Reinforced concrete is useful as it requires no painting at all, but is rather heavy when large spans have to be erected. Large clamps are necessary to fix the apparatus to concrete beams which tends to increase the cost.

Central Electricity Board "Grid" Sub-Stations. The extra high-tension and medium-tension sub-stations of the Grid are very good examples of the best modern practice in sub-station construction.

These 132-kV sub-stations are of three types, each containing several sub-types distinguished according to the arrangement of the connexions and each denoted by a special nomenclature. This is made up of three figures and two letters. Thus



SUB-STATION. Fig. 2 (left). Connexions of three circuit breaker 132-kV "Grid" sub-station. Fig. 3 (right). Connexions of single circuit breaker "Grid" sub-station. The two isolating switches in series allow for cleaning as each isolates the other.

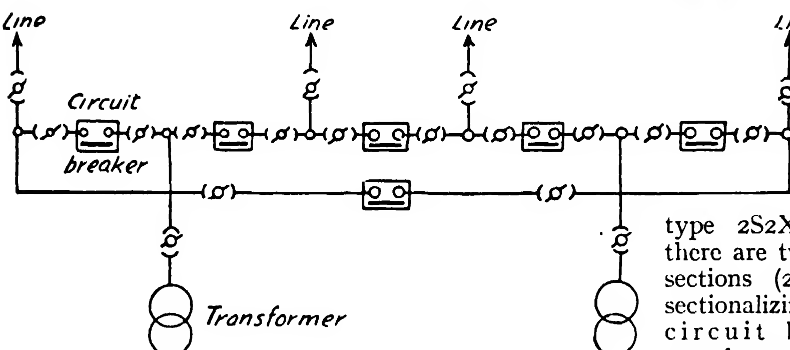


Fig. 4. Connexions of typical mesh type of 132-kV "Grid" sub-station.

type 2S2X1 denotes that there are two feeders or line sections (2), coupled by a sectionalizing switch or circuit breaker (S), two transformers (2), and one cross-over (X). The final figure (1) denotes the total number of high-tension circuit breakers.

These are known as "cross-over" stations. Type 3S2M6 has three feeders or line sections and two transformers connected in mesh by 6 section and transformer circuit breakers. Such stations are known as "mesh" stations.

Finally there are larger stations in which duplicate bus-bars are used. 4B2D7, for instance, provides for bar coupling of four line sections and two transformers on to main and auxiliary bus-bars through six line and transformer circuit breakers and one bus coupling switch.

In general, medium construction is used for cross-over and mesh stations, while for bus-bar stations high construction is used.

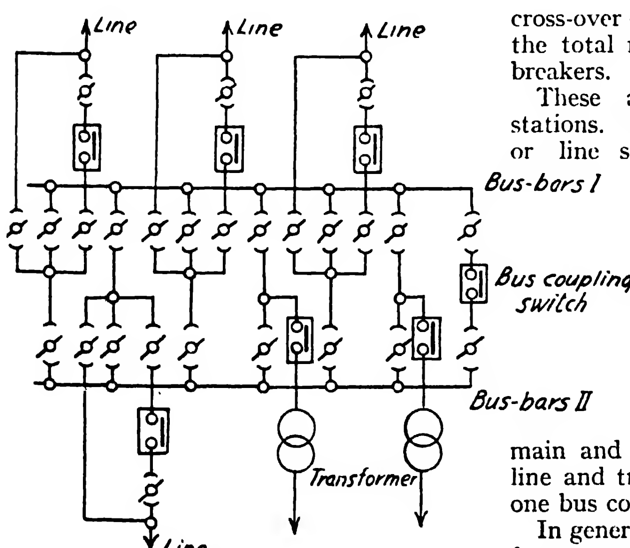


Fig. 5. Schematic arrangement of connexions of duplicate bus-bar type of "Grid" sub-station.

Automatic Sub-Stations

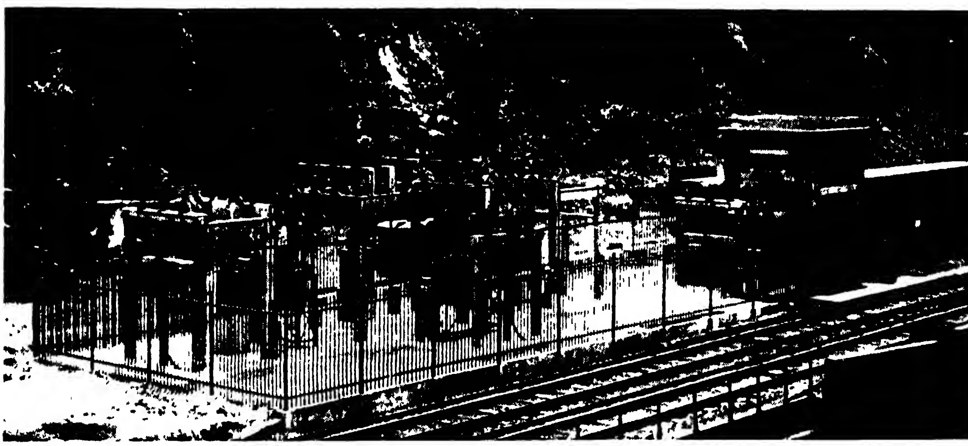
The replacement of attendants in sub-stations by automatic machinery is being pursued more and more actively, and the argument for automatic sub-stations can be based upon many considerations both economic and technical.

The economic advantages of automatic sub-stations are, of course, the decisive factor leading to their adoption, although technically they have so many good points that even at equal cost a very good case could be made for their use.

Comparative Costs. If a sub-station is manually operated an attendant must be present whenever machines are started up or shut down, and must be available at any time during the day or night in case of failure of any apparatus. If a single attendant only is employed he must therefore live in or adjacent to the sub-station, so that he can be alarmed if a breakdown occurs during the night. If constant attendance is required, it is necessary to have two or three attendants working in shifts. Capitalized on the basis of a salary of £5 per week, a house for the attendant at £400 plus rates, and certain necessary constructional features in the station itself, the total involved in the employment of a single attendant may amount to £6,200.

Suppose now a sub-station contains three rotary converters. The extra cost of equipping these for full automatic operation, with automatic reclosing circuit breakers and a complete set of safety devices and interlocking, would not exceed about £400 per set, making a total of £1,200 for the station. The necessary attendance could be provided by an electrician visiting a series of sub-stations in rotation; assuming that he had six to visit, each would then have to bear one-sixth of the charge due to the attendant, say £1,000, making a total of £2,200 per station, as compared with £6,200 if a whole-time attendant were employed.

A great advantage of automatic sub-stations is that their unit capacity can be kept smaller and their number increased as compared with manual stations, and that they can thus be situated nearer the load. The possibility of installing automatic sub-stations in positions (underground, in cellars, and so on) where it would not be possible for attendants to remain permanently, frequently enables the capacity of existing distribution networks to be so increased by the provision of a number of small sub-stations near the heaviest load concentrations, that it becomes possible to meet the growth of load without laying new feeders, a measure which otherwise would be necessary.

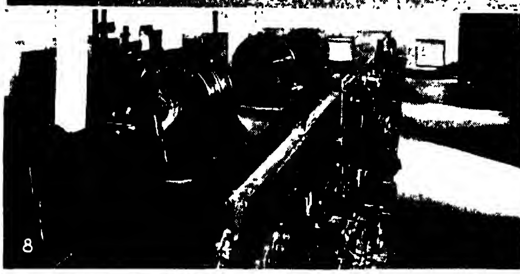


SUB-STATION. Fig. 6. Mercury-arc rectifier sub-station on the Southern Railway at Star Lane. Operated by remote control, each sub-station being fed from the "Grid" at 33,000 v. Special features are E.H.T. outdoor switchgear and transformers with indoor 2,500 kW. steel tank mercury-arc rectifiers and high speed circuit breakers. The building containing the indoor equipment is seen on the right

Courtesy of the Southern Railway

The chief technical advantages of automatic stations are the increased reliability that can be obtained, the more economical utilization of the apparatus which can be started and shut down at

Fig. 7. A 132-kV "Grid" sub-station, medium "high" construction type



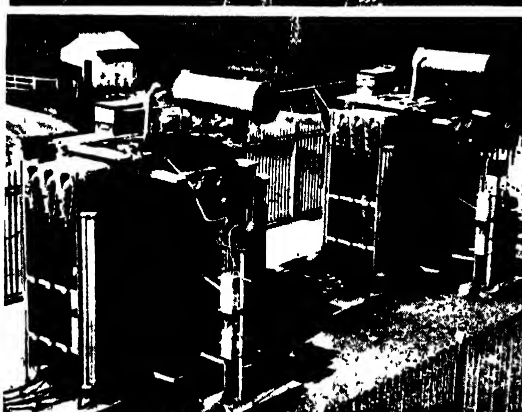


Fig. 8 4,000-kW, 1 5-kV automatic sub-station with open-type camshaft controllers. Fig 9. Duplicate 5,000-kVA, 33,000 11,000-volt outdoor transformer, small "Grid" sub-station. Fig 10 A 132-kV "Grid" sub-station, "high" construction, showing oil circuit breakers and above them the bus-bars and isolating switches

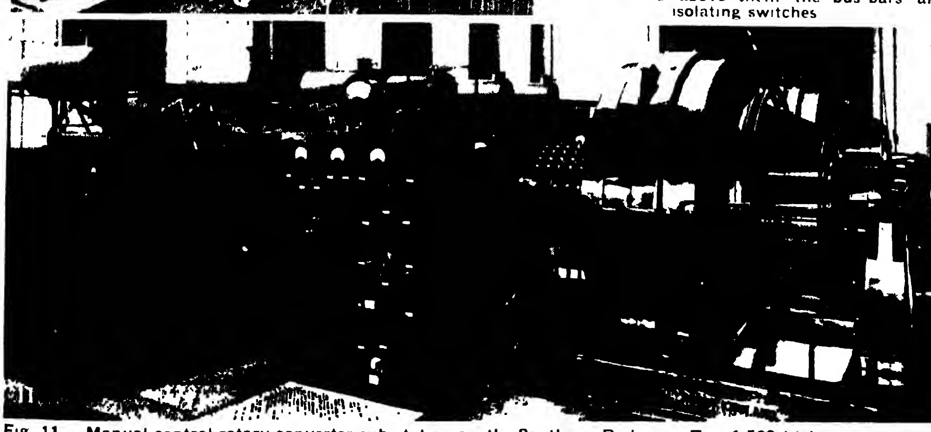


Fig. 11. Manual control rotary converter sub-station on the Southern Railway. Two 1,500-kW. converters are employed to transform 11,000 v. 3-phase 25 cycles A.C. into 660 volts D.C. The positive bus-bars are connected through high speed circuit breakers of 3,200 amps. capacity.

SUB-STATION: AUTOMATIC AND OUTDOOR TYPES

Courtesy of The ral Electric Co., Ltd., Johns & Philips, Ltd., English Elec Ltd., and Southern Railway

To face page 1174

the instant required by the load, without waiting for the attendant, better voltage regulation than is easily obtainable with hand operation, and finally quicker restoration of service after breakdowns.

In automatic sub-stations very complete arrangements are made for automatically setting out of service any machine which overheats or in any way becomes defective.

Operation of Automatic Sub-Stations. The functions that an automatic control equipment in a sub-station must perform are roughly as follows:

(1) It must set in operation a sufficient capacity of plant just to meet the load at any instant and thus utilize the available machinery in the most economical manner possible;

(2) while in service it must supply power to the distribution network at constant voltage;

(3) it must shut down the plant immediately a decrease of load allows it;

(4) it must diagnose and remedy any fault that may occur, either by clearing the fault and restarting the affected machinery, or if the machinery itself is faulty, by shutting it down and replacing it with other units.

The type of converting machinery in the sub-station, whether rotary converters, motor converters, rectifiers, and so on, does not affect the principles upon which the operation of the automatic gear is based. Descriptions of the different forms of converting machinery will be found under the headings Converter; Mercury Arc Rectifier; Transformer, etc.

The operations which have to be performed automatically vary, of course, with the type of machinery in use.

If transformers alone are used the necessary manipulations are confined to opening and closing H.T. and L.T. circuit breakers and supervising the temperature of the transformers, and so on.

If, as is more commonly the case with automatic sub-stations, rotating converting machinery is used, the operations are more complicated. The units must be started up, synchronized on the A.C. side, and then paralleled on the D.C. side.

Functioning of Automatic Apparatus. This may be divided into three headings:

(A) the initiation of starting up and shutting down;

(B) the process of starting up and shutting down;

(C) the operation of safety devices.

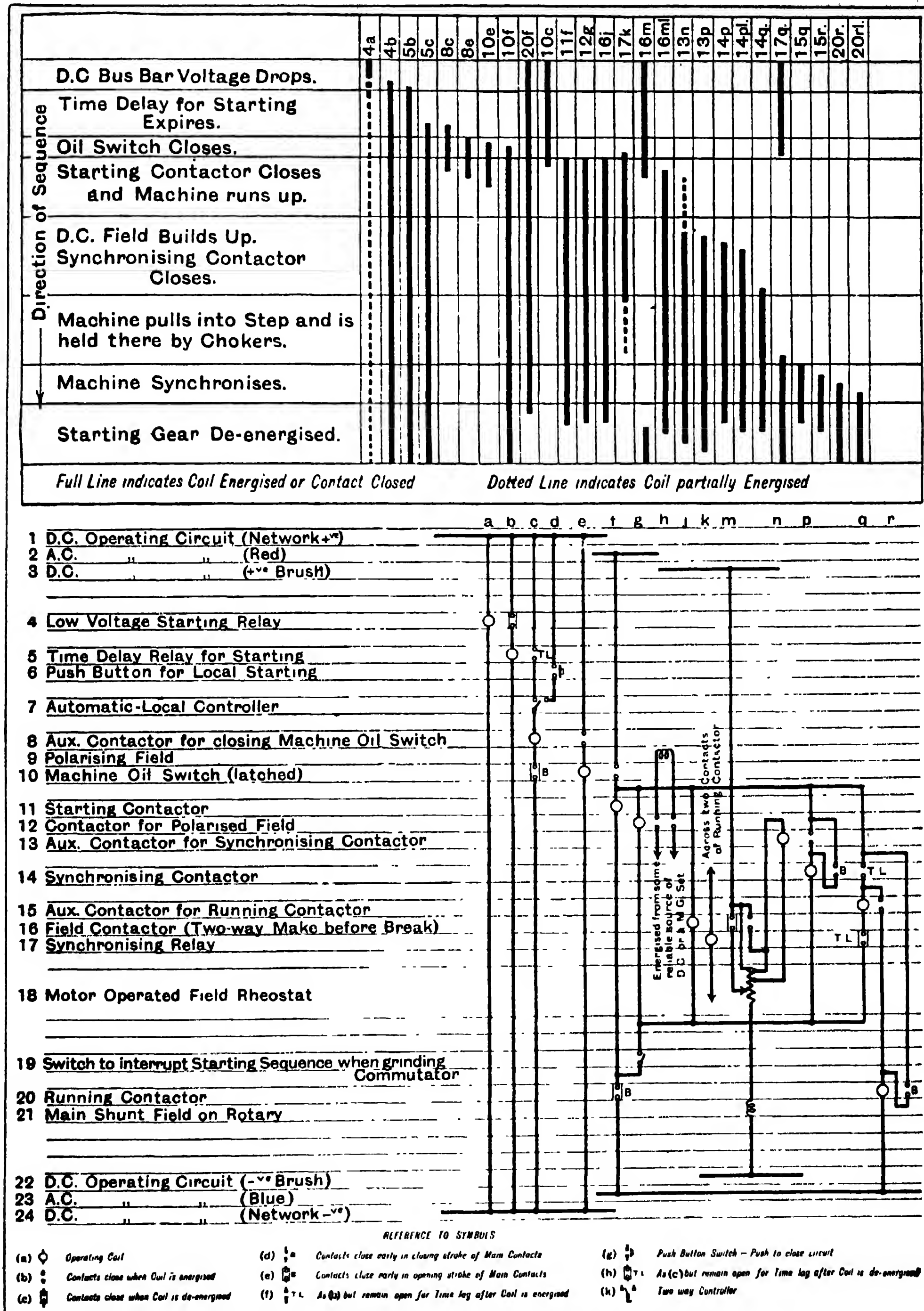
(A) The need for putting into service more converting machinery may be indicated either by the voltage on the line falling below the statutory limit, or by the output of the machines actually running exceeding a certain value. Relays are therefore used which react to such changes of conditions, and give impulses which initiate the process of starting up additional plant. It is desirable that temporary fluctuations of voltage or load should not result in machines being started up. In order to prevent this, all such relays are provided with time lags of one to three minutes, so that they do not close their contacts unless the variation lasts for a time in excess of the lag.

There are many types of load which fluctuate more or less regularly at the same times every day. In such cases the relay control may sometimes be combined advantageously with time-switch control. The time switch may, for instance, be used to start up additional machinery a few minutes in advance of the time at which it is known that a large increase of load regularly occurs.

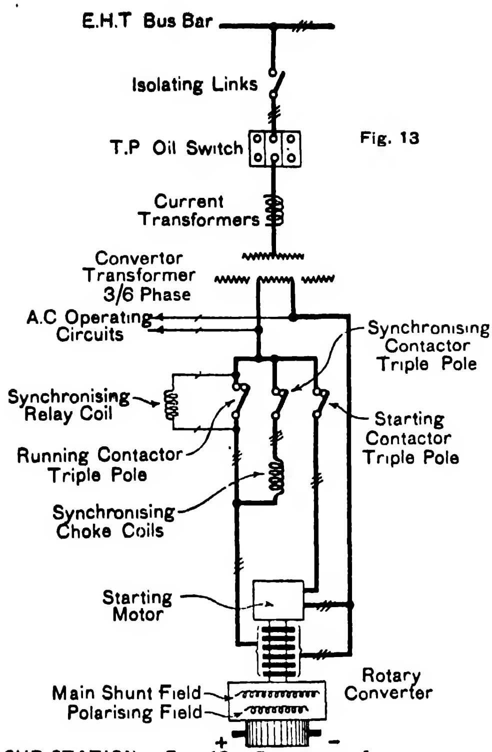
In some cases it is thought desirable that the running of plant in the sub-stations should not be entirely automatic, but to a greater or less extent under the control of an operator in some central position. This is where one of the several systems of remote or supervisory control may be used.

Where the only operations that it is desired to perform are the starting up and stopping of machines, and perhaps the reading of a summation wattmeter for the sub-station load, ordinary remote control with multicore cables may be used.

In this system, the starting up and shutting down impulses come from the central control station instead of from relays in the sub-station itself. The actual starting, synchronizing, and shutting down of the machinery is done automatically as in fully automatic sub-stations; an indication whether each machine is running or idle and its load or any other factor can then be transmitted to the control station and shown on a control board.



SUB-STATION. Fig. 12. Principle of "interlock" type of automatic gear as applied to a rotary converter. The sequence of operation is: (1) Starting impulse received: (a) By distant control; (b) By low D.C. voltage on bus-bars (time delay fitted); (c) Time switch. (2) Oil switch closes. (3) Main transformer energized. (4) Starting contactor closes. (5) Machine runs up. (6) Synchronizing contactor closes. (7) Machine is pulled into synchronism and held there. (8) Running contactor closes. (9) Machine parallels. (Detailed key above.)



SUB-STATION. Fig. 13. Diagram of main connexions for scheme illustrated in Fig. 12.

When it is desired to indicate more factors, or the sub-stations are large and complicated, or where they are very numerous or situated at considerable distances from the control station, the use of pilot wires or cables becomes prohibitively expensive. When this is so, recourse can be had to automatic telephone equipment for a solution.

The principle of automatic telephones (*q.v.*) is to allow of the selection by each transmitter of one out of any number of receivers, and the principle can be extended to allow of controlling at a distance any number of factors by means of a very limited number of connecting wires. Such a system is known as supervisory control (*see below*).

Starting and Stopping the Converters. (B) Starting up and shutting down a converter involves carrying out a number of operations in the correct sequence and at prescribed intervals. There are two methods of doing this which are generally used. These are:

(1) The "interlock" method. Here the sequence of operations is assured by a number of auxiliary or interlock contacts on each main switch and contactor. Thus the closing or opening of each main contact initiates the opening or closing of those which should follow it.

(2) The second is the "controller" method. Here the interlock contacts are partially or wholly replaced by contacts on a drum controller. This is started and stopped and rotated at such a speed that the sequence of operations is carried out correctly.

The interlock system has the advantage of being more straightforward; in addition no operation can take place until those preceding it have been correctly completed; on the other hand the use of the controller enables the auxiliary wiring to be considerably simplified, and the auxiliary contacts to be concentrated in one piece of apparatus instead of scattered over the installation.

Protection of Automatic Sub-Stations. (C) In order to protect plant which runs the greater part of its time without supervision, a complete system of safety devices must be used. As far as possible, these should be so arranged that there is a double protection against each possible type of fault. In this way damage due to the failure of a safety device becomes almost impossible.

Faults may be divided into two classes:

(1) Those which are not due to failures in the sub-station, *e.g.*:

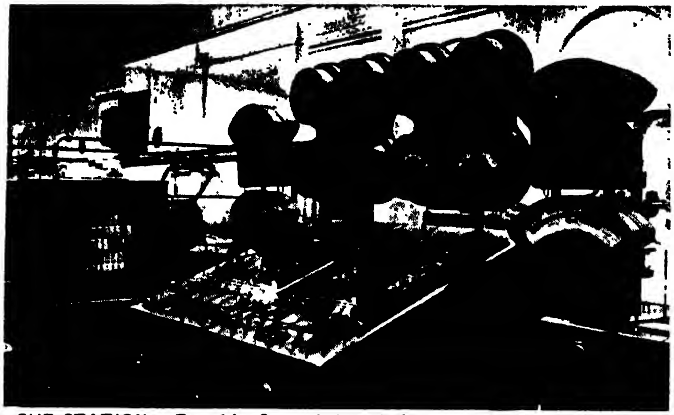
Low A C. volts (H.T.),
Interruption of supply on one phase only,
H.T. A C. overload,
D C overload.

The protective apparatus is so arranged as to shut down the plant on such a fault occurring and allow it to start up again after a certain interval and after the fault has been cleared.

(2) Those which occur in the sub-station, *e.g.*:

Leakage to earth on machines or transformers,
Faulty start,
Failure of field circuit on machines,
Overspeed,
Reversed polarity,
Overheating of bearings, windings, transformers, etc.

Here the protective devices are arranged in some cases to shut down the machine in question immediately, and prevent it restarting until it has been inspected and



SUB-STATION. Fig. 14. Control board for supervisory control of two sub-stations. The cabinet containing the relays, etc., is behind. *General Electric Co., Ltd., of England.*

the relays reset manually, or the machine may be shut down and restarted after an interval. If the fault still persists it will shut down again. This process may be repeated say three times, after which if the fault still persists it is shut down and locked out.

Supervisory Control. The principle of this system is to allot a distinctive number to every operation which it is desired to perform in each sub-station, just as on a telephone system each subscriber has his number. The control switches are then arranged so that each dials automatically the number corresponding to the operation which it performs. This results in the connexion being made which enables the desired operation to be effected.

Similarly, if it is desired to read an instrument, depression of a key belonging to it selects the corresponding circuit in the sub-station and makes the connexion automatically. An important feature of the best supervisory control systems is an automatic check back, which enables the operator to be certain that no error has occurred in the connexion of the control switch to the controlled apparatus. The principle is that the receiving equipment at the sub-station is duplicated at the control station, and the series of impulses which is received at the sub-station each time a control switch is operated, and results in the selection of a certain circuit to be controlled, is stored up automatically and then retransmitted to the control station, where it results in the lighting up of a signal lamp corresponding to the control switch in question. The operator thus has visual indication that the functioning of the distant control gear is correct and can proceed to carry out the operation desired with full confidence.

Traction Sub-Stations. Automatic sub-station practice with supervisory control is exemplified in mercury arc rectifier sub-stations of the Southern Railway. The outdoor section consists of the 33,000-volt E.H.T. switchgear and transformers (illustrated in page 1174), the rectifier, its switchgear and the supervisory equipment being indoors.

Each sub-station, which is one of a chain, is supplied with three phase energy at 33,000 volts 50 cycles from the "Grid" through a Southern Railway cable which is practically a ring main. At the sub-station the ring main passes through duplicate isolators and oil switches, the supply of the rectifier unit being obtained by a tee-off with its own isolator and oil switch. Each oil switch, which is motor operated, has a rupturing capacity of 500,000 kVA.

A 2,500-kW steel tank mercury arc rectifier is installed in each sub-station. High speed circuit breakers control distribution to the conductor rails

The supervisory equipment consists of a synchronized selector and associated relays, a large number of switches being controlled through the same pilot wires.

A rotary converter sub-station on the Southern Railway is illustrated in the Plate facing p. 1174

Source of Power for Control Apparatus. The control apparatus of an automatic sub-station requires a source of current available at the instant the station is started up and remaining available in a breakdown. There are a number of alternatives:

1. A storage battery. 2. An auxiliary transformer fed from the H.T. supply. 3. The L.T. side of the main transformer. 4. The D.C. bus-bars. 5. The D.C. terminals of the converter.

Storage batteries are not suitable for automatic stations as they require too

much attention. The scheme most generally adopted is to use (2) for operating the A.C. circuit breakers and a combination of (4) and (5) for closing the D.C. circuit breakers and so on.

The interested reader is referred to the following papers for more detailed descriptions of sub-station practice:

"The Lower-Voltage Sections of the British Grid System," by C W Marshall, J I E E, vol. 74, p 105.

"The Construction of the 'Grid' Transmission System in Great Britain," J. Wright and C. W. Marshall, J I E E, vol. 67, p 685

"The Design of Static Sub-stations for High Voltages," C E Atkinson, J.I E E, March, 1927, p 253

"The Design of City Distribution Systems," J. R. Beard and T G N Haldane, J I E.E, vol 65, p 97

"The Design of Static Sub-stations with some notes on their Equipment," N. Thornton, J I E.E., Nov, 1924, p 37

SULPHATING. Popularly, a sulphated cell is one badly over-discharged, but the lead-acid cell operates only because it becomes sulphated. Consequently, sulphating is a matter of degree, which, provided it does not continue beyond the safe voltage discharge limit, is necessary and normal. Only when discharging continues beyond the safe limit, when the cell is stood aside in a discharged state, or when impurities are in the electrolyte, does harmful sulphation occur. This latter condition is known as *over-sulphation* and is generally indicated by the plates becoming white, first in spots and then covered by a continuous white layer in aggravated cases. This condition is very difficult to remedy and prevention is therefore essential. The best way to keep a lead-acid cell healthy is to have it in continual though proper use (*see* Charging and Charging Systems).

Charging over-sulphated cells at low rates will often improve their condition, but it must be continued until cell voltage ceases to rise further, and the process may take up to three days or more to complete.

SUMMATION OF A.C. LOADS. A device or arrangement for obtaining in one meter a registration corresponding to the aggregate energy or reactive volt-ampère-hours carried by a number of independent circuits fed from a single source of supply. Summation metering equipments are used extensively to measure maximum demand in kVA when supplies from the "Grid" are obtained through two or more feeders. To obtain this demand, it is necessary to know the aggregate demand on the several circuits both in kW and in kVAh. There are several methods available for the summation of the loads in two or more circuits. These are briefly described:

(a) A meter may be used with several windings each connected to a current transformer in one of the circuits whose load is to be aggregated. This method requires non-standard instruments and is not favoured.

(b) When the rated primary currents of all the circuits are the same, the secondary windings of the current transformers can be all connected in parallel to the current coil of a summation meter. This method is not suitable if the ratings of the circuits differ, and it is liable to errors of a similar character to those explained under Summation Transformer if the circuits are unequally loaded.

(c) A single meter may be supplied from the secondary of a summation current transformer (*q.v.*).

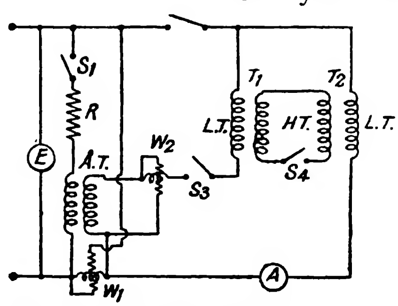
(d) When two circuits only have to be aggregated, a double meter can be used which consists of two 3-phase combinations communicating torque to a single moving system.

(e) The system used for the "Grid" can be described as electro-mechanical. Here a meter in each of the circuits whose load is to be aggregated communicates an impulse to the summation meter for each revolution it makes by means of a light contact on the moving element. Each impulse advances the summation meter the correct amount by a step by step process. The summation meter is so designed that, if two impulses are received simultaneously, they are both registered. By the use of both energy and reactive meters in the individual circuits, the aggregate kWh and reactive kVAh are obtained.

SUMMATION TRANSFORMER. A current transformer whose secondary current is proportional to the vector sum of the currents in its several primary windings. A summation transformer has a number of primary windings which are usually connected in the secondary circuits

of the current transformers of the main circuits whose loads are required to be aggregated. If the main currents have different ratios, the numbers of the turns on the primary windings of the summation transformer are in the proportion of the rated primary currents of the respective current transformers. The secondary circuit of the summation transformer then has its maximum rated value when all the main circuits are carrying their rated currents.

The errors of the secondary current of a summation transformer are due to both the error of the summation transformer itself and to those of the main transformers. There is an additional error if the currents in the main circuits are not in proportion to their rated values, the nature of which will be understood if it be assumed that one of these main circuits is open and carries no current. In this condition there will be no E.M.F. induced in the secondary of the current transformer in the idle circuit. This secondary will then behave as an additional secondary circuit of high impedance to the summation transformer, and it will divert from the true secondary circuit a small proportion of the current produced by the main circuits which are carrying load. The summation transformer is not, therefore, a very accurate method of aggregating the loads carried by a number of circuits.



SUMPNER'S METHOD. Connexions for the efficiency test.

SUMPNER'S METHOD : of Transformer Testing. This is a method for determining the efficiency of two similar transformers in which the losses are measured directly. The method is analogous to Hopkinson's test for dynamos and is shown diagrammatically above for two single-phase transformers. Each transformer supplies power to the other, but being connected back-to-back (or in opposition) the power drawn from the mains is only that required for supplying the sum total losses of the two. In the diagram, T_1 and T_2 are the transformers under test, the low-voltage windings both being connected in parallel across the supply and the high-voltage windings to each other in opposition. The L.T. winding of T_1 is connected in series with the secondary winding of an auxiliary transformer A.T., the function of which is to raise or lower the voltage across the L.T. winding of T_1 so that the H.T. voltage is different to the voltage across the H.T. winding of T_2. Currents will circulate in the transformer windings depending upon the difference in voltages. The voltage across the secondary of A.T. can be regulated by the variable resistance R.

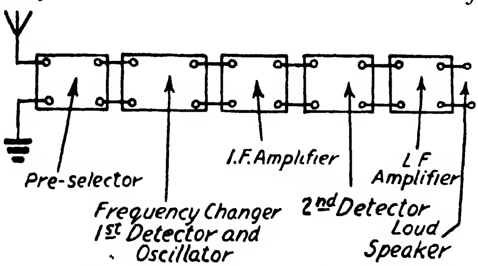
The currents in the primaries of T_1 and T_2 are in opposite directions, so that the net current drawn from the mains is only that required to supply the losses of the two and the magnetizing currents. Wattmeter W_1 measures the total power taken by T_1 and T_2, while W_2 measures the power supplied by A.T. With all switches closed, except S_1, and the secondary of A.T. temporarily short-circuited, W_1 will read the total no-load losses of T_1 and T_2, and the ammeter A, the no-load current of T_2. If S_1 now be closed, the temporary short circuit across A.T. removed, and R adjusted to give various load current readings on A, W_1 gives the watts iron loss and W_2 the watts copper loss of T_1 and T_2.

The total losses are the sum of the wattmeter readings. The load on T2 is the product of the voltmeter and ammeter readings. The losses in leads and instruments should be deducted from the reading of W_2. The efficiency of each transformer is then output $\div$ (output + $\frac{1}{2}$ total losses). *See* Hopkinson's Test.

SUPERHETERODYNE RECEPTION. The special feature of superheterodyne reception compared with other systems is the incorporation of a frequency-changing device which converts the frequency of all received signals, whatever the wave-length, to a definite fixed radio frequency, different from that of the received signal and usually of a lower value. The new frequency is referred to as the " intermediate frequency " (I.F.), and the main degree of H.F. amplification is effected at the intermediate frequency

before the signals are applied to the detector proper.

The first advantage to be gained from such a system is that it enables the necessary



SUPERHETERODYNE RECEPTION. Fig. 1. Schematic diagram illustrating the successive stages in a "superhet."

degree of H.F. amplification to be effected at a frequency more convenient than the original frequency, as far as efficiency and selectivity per stage is concerned—much higher amplification and selectivity per stage are possible at lower radio frequencies than at high ones, and stability is more easily attained. For these reasons the intermediate frequency is nearly always chosen to be considerably lower than the lowest signal frequency to be received. An exception to this rule is to be found in single-span tuning (*q.v.*). For reasons connected with interference an intermediate frequency of about 110 kc. is usually adopted for reception of European broadcasting. So in a superheterodyne broadcast receiver all signals in the broadcasting bands between 1,500 and 150 kc. have their frequencies changed to 110 kc.

A second advantage is that the intermediate frequency amplifier is required to operate at a single frequency only, requiring no variable tuning and involving more or less constant sensitivity, selectivity and quality of reproduction for all signal frequencies. The return of the superheterodyne to popularity is mainly due to the advent of band-pass tuning. The inclusion of band-pass filters in the intermediate frequency amplifier enables the inherently high selectivity of the lower radio-frequency circuits to be retained, whilst at the same time eliminating the severe side-band cutting associated with ordinary tuned circuits of high selectivity. Other factors are the practicability of ganged controls and the introduction of special frequency changer valves of the heptode or pentagrid class.

Principles of Operation. The various stages are indicated in Fig. 1, and a skeleton circuit is given in Fig. 2.

The pre-selector stage may or may not incorporate a stage of H.F. amplification at the received signal frequency. In any case this portion is identically the same as for an ordinary "straight" receiver. Where extreme selectivity is required the signal frequency circuits include band-pass tuning and a stage of H.F. amplification.

The Frequency Changer. The nucleus of the superheterodyne receiver is the frequency changing device which always operates on the heterodyne principle (*q.v.*). It therefore comprises a generator of continuous oscillations (the oscillator) and a rectifier. In some types these functions are performed by separate valves and in others a single multi-grid valve is used, but the principle is the same in both cases.

Both the locally generated oscillations and the received signal oscillations are applied to the rectifier, which is usually known as the first detector. They combine, and when rectified give a beat frequency equal to the difference between oscillator and signal frequencies. *The modulation frequencies of the original signals are still retained in the new intermediate-frequency variations.*

Suppose that a 300-metre signal is being received, its frequency being 1,000 kc., and that the intermediate frequency is 110 kc.

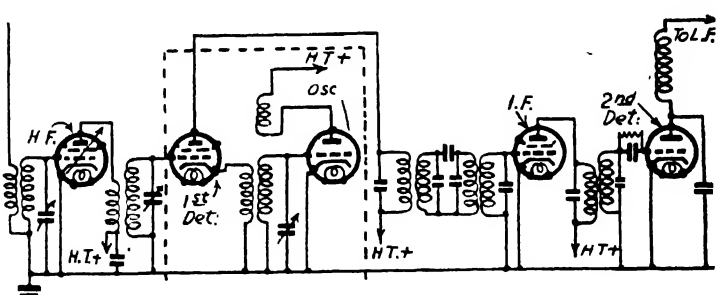


Fig. 2. Skeleton diagram of superheterodyne circuit. Portion enclosed by the dotted line comprises the frequency changer (1st detector and oscillator).
Courtesy of "The Wireless World"

Then the oscillator frequency must be either 1,110 kc. or 890 kc. Thus if the oscillator variable condenser were not ganged to the tuning condenser(s) of the pre-selector circuit there would be two possible settings of the former for the reception of any one station. With ganged tuning, however, this effect is not possible. Ganged tuning condensers for superheterodynes have one section with the vanes differently shaped from those of the remaining sections so as to give the required frequency difference of 110 kc. over the whole tuning range.

In the skeleton diagram of Fig. 2, separate 1st detector and oscillator valves are shown in the frequency changer, which comprises the portion enclosed by the dotted lines. The local oscillations are conveniently fed to the 1st detector *via* the cathode with indirectly heated valves.

The intermediate-frequency amplifier possesses no special features other than that no variable tuning is necessary. The band-pass filter(s) comprising the intervalve circuits may have adjustable coupling to enable the best compromise to be effected between selectivity and quality under receiving conditions. The 2nd detector or detector proper separates out the required audio-frequency variations from the intermediate frequency and the succeeding L.F. and output circuits are conventional. Automatic volume control is usually incorporated in modern receivers.

Second Channel Interference. It will be realized that an oscillator frequency of, say, 1,110 kc. will produce a beat frequency of 110 kc. not only with a 1,000 kc. signal frequency but also with a signal frequency of 1,220 kc. Thus two stations working at these frequencies would be received simultaneously if the pre-selector circuit referred to were not included, and for this reason an initial H.F. stage is frequently incorporated when a high degree of selectivity and freedom from "second channel interference" is necessary.

The superheterodyne is necessarily somewhat more complicated than the straight receiver, but once the initial adjustments of ganging, etc., are correctly made no more trouble should be experienced than with a multivalve "straight" set. It should be remembered, however, that the ganged condensers must be so "trimmed" that the same frequency separation (110 kc. in the example given) occurs over the whole range. If the receiver develops miscellaneous heterodyne whistles and loses sensitivity over part or all of the tuning range, in all probability the ganging has got out of adjustment and should be investigated.

SUPERSCALE INSTRUMENTS. The trade name of a type of indicating instrument of the moving-coil or moving-iron types, manufactured by Everett Edgcumbe & Co., Ltd., in which the angle subtended by the scale is somewhat greater than that of the earlier types. The increased length of scale for a given size of case is obtained by a slight modification of the design, and instruments with this characteristic are now supplied under similar trade names by most other manufacturers.

SUPERSONIC FREQUENCY. The term used to describe any electrical frequency too high to produce audible sound waves in a sound-reproducing system.

SUPPLY MAIN. The supply main consists of the cables and other conductors forming part of a supply authority's transmission or distribution scheme, extending from the generating station to the consumer's terminals, where his own installation commences. Every installation needs to be adequately protected by suitable controlling apparatus, easily accessible to the consumer and situated as near as possible to the point of entry of the supply main. The general question of supply is dealt with under the heading Distribution. *See further under* Feeder, "Grid" System; Overhead Lines; Power Station, Service Cable, Transmission, *etc.*

SURFACE FLEXIBLE SYSTEM. Wiring to lights and switches by means of twisted flexible cords was at one time very popular on the Continent and in America. The outer braiding of the cord was generally of hard cotton braiding, which lends itself to the application of paint rather better than the more porous silk. The wires were as a rule fixed to the wall surface by means of china studs inserted betwixt the spirals of the flexible cords.

In Britain, surface flexible wiring has been confined chiefly to temporary installations and extensions. Here the cords are more often led through screwed brass

eyelets containing small china ring insulators. Suitable surface switches and ceiling roses are available provided with side channels for the wire entry.

By I.E.E. Regs. 404 and 405 high insulation flexible cords may be used for low-pressure sub-circuits and that if pure rubber is employed they must not be used in damp places. These regulations indicate that three feet is the maximum spacing for insulators. Circuits wired or partially wired with flexible cord should be open to view throughout their length except where passing through floors or division walls, where they must be protected by non-ignitable damp-proof conduits. More durable effects are got when the flexible cord is protected with cab-tire sheathing of circular section or when there is an outer armour of braided brass or galvanized steel wire. These more robust varieties of surface flexible are generally secured by means of metal saddles or clips. *See* Flexible, Wiring.

SURGE. A surge is the name commonly given to the transient conditions arising in an electric circuit which serve to connect one state of circuit equilibrium with a sudden change to a different state. Surges occur in all electric circuits whenever a change takes place in the stable conditions, but they are of greater magnitudes and more likely to be disastrous in their effects in A.C. systems on account of the greater sizes and extents of such systems. Surges vary enormously in intensity, ranging from the innocuous transient arc at the opening of a 5-amp. tumbler switch to the short-circuit current transients which may wreck large generators and transformers or to the terrifying effects of a tropical thunderstorm.

Nature of Surges. Surges of voltage, current and energy may occur and they may produce failures in the dielectric, electric or magnetic circuits of plant, overhead lines and cables. They may take place to earth or may be confined within the system. Surges are said to occur in time or in space; the former has reference to such a case as the distribution, in terms of time (microseconds), of a transient voltage wave through a transformer or generator winding, while the latter applies more particularly to the study of transient waves on long transmission lines and cables in which wave amplitudes may vary considerably at points widely distant apart. It is, of course, always possible to correlate the time and space dimensions.

The general nature of a surge is, then, a transitory passage of voltage and current, usually, though not necessarily, of relatively high amplitude and often of high frequency or equivalent to high frequency. It may be a travelling wave, a standing wave or an oscillation which in the latter case may be damped or undamped or consist of a recurrent train of waves. It is not possible in the present work to discuss the theory of transients in any great detail, so that the interested reader is referred to the two books by the late Dr. C. P. Steinmetz, entitled "Theory and Calculation of Transient Electric Phenomena and Oscillations" and "Electric Discharges, Waves and Impulses and other Oscillations."

Typical transient wave shapes are shown in Figs. 1 to 5 inclusive.

Causes of Surges. Surge waves are caused by short circuits, flash-over of line insulators due to lightning-induced voltages or system faults, insulation failures, faulty synchronism of rotating machines, sudden load variations, all forms of switching, momentary resonance

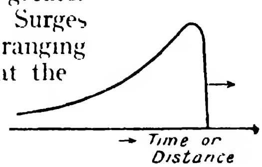


Fig. 1

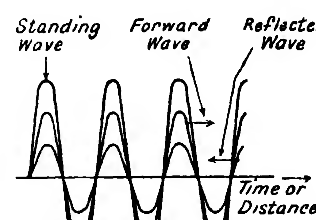


Fig. 2

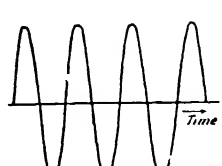


Fig. 3

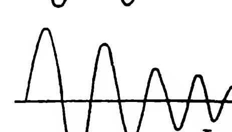


Fig. 4

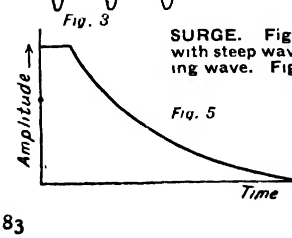


Fig. 5

SURGE. Fig. 1. Travelling wave with steep wave front. Fig. 2. Standing wave. Fig. 3. Undamped oscillation. Fig. 4. Damped oscillation. Fig. 5. Unidirectional transient.

due to switching, blowing of fuses, the operation of electric arc furnaces, and in fact to any circumstance which involves a change in the stable running conditions of a circuit.

Dangers of Surges. The dangers to be apprehended from surges are insulation failures in the case of high-voltage surges and the melting and distortion of conductors when high-current surges occur. Surges arising from lightning-induced voltages on transmission lines are typical of the first kind and those resulting from short circuits on large power systems represent the second.

The provisions made for counteracting the effects of voltage and current surges are as follows:

Protection Against Voltage Surges. For voltage surges, the insulation of all components of the power system is proportioned to give a reasonable factor of safety against breakdown and in locations where trouble (due to lightning, for instance) is likely, special high insulation levels are adopted. In addition, overhead lines may be protected by continuous earth wires run above or below the power wires. For the same distance between the power conductor and the earth wire either position gives the same degree of protection against lightning-induced voltages; protection against direct strokes is only achieved, however, by running the earth wire above the power lines. The degree of protection increases with the number of earth wires, but it is seldom economical to run more than two earth wires on extra high voltage lines.

Lightning arresters, choke coils and condensers are all used to protect plant against the effects of voltage surges. Arresters range from the simple horn-gap arrester to the more modern forms, such as the Pellet arrester, the Autovalve arrester, the Thyrite arrester and the Crystal Valve arrester. The requirement of a good arrester is that it shall have a minimum time lag of discharge and a valve action so that power current does not follow the discharge of surge current. The arresters are connected from the line conductors to earth through spark-gaps and function to discharge a disturbance to earth when the voltage on the line reaches such a value as to cause the arrester spark-gaps to arc over.

Choke coils may be connected in series with the power line as auxiliaries to lightning arresters, in which case they build up the surge voltage across the arrester gaps, or they may be used alone to smooth down the front of the surge wave. In the latter case, the coils are much larger than in the former in order to provide the requisite smoothing inductance. As an alternative to series choke coils, static condensers may be shunted from the lines to earth to serve the same wave front smoothing purpose.

The choke coils may be fitted with shunted resistances, while the condensers may be fitted with series resistance to absorb the energy of the disturbing waves.

A further type of surge protective apparatus is the so-called surge absorber, which is, in effect, a resistance shunted choke coil or a condenser with series resistance. Such a device absorbs the energy of the transient, it reduces the maximum amplitude and smooths down the wave front of the voltage surge.

On very high voltage lines, schemes of co-ordination of insulation levels are adopted so that the most vulnerable parts of the system, *i.e.* the internal parts of transformers, generators and circuit breakers, are protected by flashing over, under surge conditions, of those parts, *i.e.* line insulators, bushings, arrester gaps, which are able to withstand such action.

Protection Against Current Surges. This is achieved by the inclusion of series reactance coils so proportioned as to withstand the thermal and electro-magnetic stresses to which they may be subjected during short-circuit conditions on the system. Such coils are described in page 995, and it need only be said here that the conductors must be extremely well braced so as to present a rigid structure which will withstand the abnormal forces which occur on large power systems. *See* Arrester; Capacity; Oscillation; Protective Devices; Reactor; Static.

SURGE ARRESTER. Surge arrester or lightning arrester is a piece of apparatus used for protecting plant and equipment from the effects of transient electrical disturbances which are classed

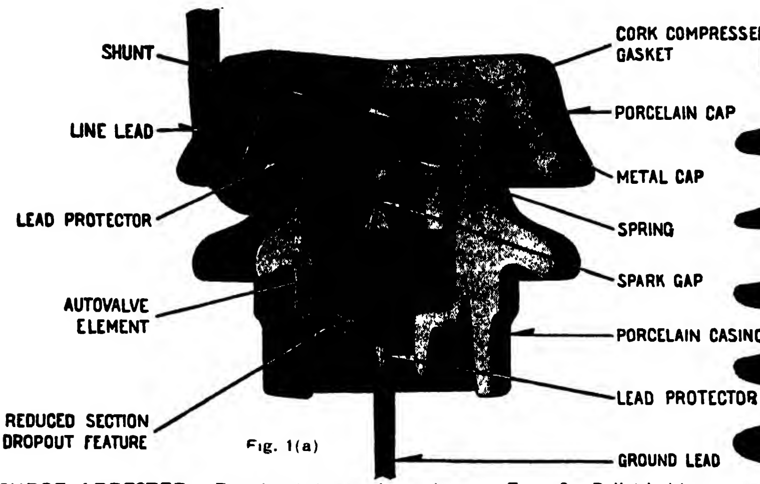


Fig. 1(a)

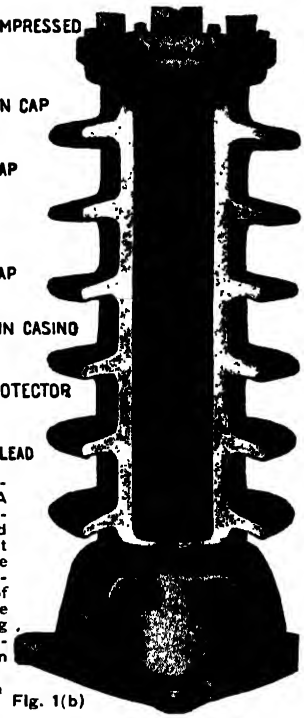


Fig. 1(b)

SURGE ARRESTER. Fig. 1 (a) Internal construction of 3-kV. Autovalve distribution type arrester (b) Part of phase leg showing the porous block discharging element of a 73-kV. Autovalve arrester.
Westinghouse Electric & Manufacturing Co., Ltd.

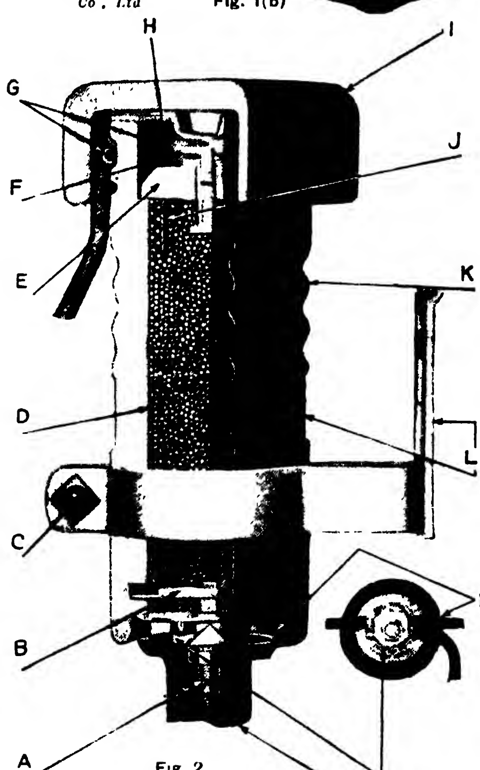


Fig. 2

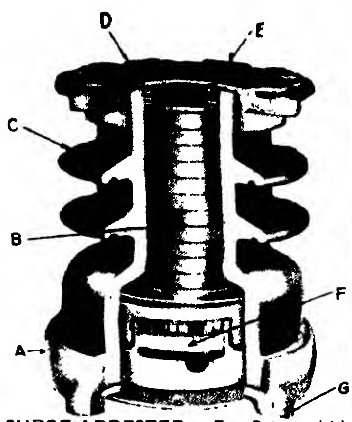
Fig. 2. Pellet lightning arrester. A column of litharge-coated pellets of lead peroxide is in contact with a series gap. The resistance of the column is a function of voltage only, thus the current passing increases proportionately with the rise in surge voltage.
British Thomson Houston Co., Ltd

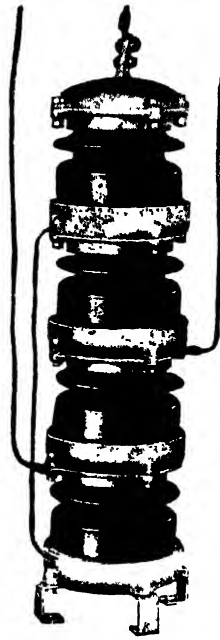
generally as surges. The surges may be due to transient conditions internal to the system or originating external thereto. The design of surge arresters makes use of the characteristics of resistance, inductance and capacitance in different combinations or singly. The simplest form is the horn gap arrester with series earth resistance to limit the flow of power current to earth.

Modern arresters for A.C. circuits possess a valve characteristic which enables them to discharge transient high voltage steep fronted disturbances freely to earth and subsequently to offer a high impedance to the flow of power current to earth, thereby stopping the latter.

Arresters are connected to the system through sphere spark gaps possessing extremely short time lags and they are shunted to earth on the line side of the plant to be protected. Modern forms of surge arresters are the Pellet oxide film arrester, the Autovalve arrester, the Thyrite arrester and the Crystal Valve arrester each being described in the next page

Another form is the surge absorber which is connected in series with the line and operates to dissipate the energy of a surge which, in one example of construction, is transferred inductively to a high resistance secondary circuit. Still other designs employ substantially proportioned inductances and capacitances with resistance in order to reduce the voltage gradients of the





SURGE ARRESTER Fig. 3 (a and b). Section and elevation of Thyrite arrester A porcelain container encloses metal-coated Thyrite discs, pressed together and in contact at the base with several series gaps, each shunted by a high resistance. Thyrite is an inorganic compound of a ceramic nature, having the characteristic of being an insulator at one voltage, but a conductor at a higher voltage. This gives a valve action that permits dissipation of surge voltages but prevents power current flow

The British Thomson-Houston Co., Ltd

transient waves which pass on to the plant to be protected, and to reduce the wave amplitudes and energy magnitudes.

The Autovalve arrester shown in Fig. 1 consists of a porous block autovalve element and a series spark gap. The element consists of one or more porous blocks in series, the number depending on the arrester rating. Each block is 1 inch thick and of either 2 inches (3 kV to 9 kV) or 4½ inches (12 kV and above) diameter and rated at 3,000 r.m.s. volts. The blocks and spark gap are assembled in a porcelain housing between metal end caps which also serve as terminals. For the higher voltages the complete arrester consists of a number of such porcelain housings with their blocks and end caps bolted together to form a series stack. The series gap is of the multiple type and the arresters are suitable for indoor or outdoor mounting.

In the Pellet type arrester, shown in Fig. 2, the elements consist of a column D of lead peroxide pellets about $\frac{3}{32}$ inch diameter, and having a thin porous coating of litharge. These, together with a series gap H, are assembled in a porcelain tube K, with metal electrodes B and F in contact with the pellets at each end. The pellet column is about 2¼ inches diameter and its length is approximately 2 inches per kV of arrester rating. Up to 20 kV the lead pellet column is contained in a single porcelain tube and above that voltage several tubes in series are used. A is locking ring; C, shouldered bolt; E, porcelain insert; G, line lead cable-socket; I, glazed porcelain cap; J, metal sleeve; L, bolt securing metal suspension bracket to cross-arm; M, openings for earth leads, N, clamp type earth terminal. These arresters also are suitable for indoor and outdoor service.

The Thyrite arrester is shown in Fig. 3. Its general assembly is similar to the Autovalve arrester, but it employs a specially manufactured discharge material called Thyrite in the form of discs 6 inches diameter by ¾ inch thick, and 3 in. diameter by 1 in. thick. The discs are coated on both sides with copper. In Fig. 3, A is aluminium bottom plate; B, Thyrite discs, spray-metal coated; C, porcelain container; D, aluminium top-plate, E, triple springs and compression plate, F, series-gap assembly, G, bosses for bolts. Thyrite is substantially a good insulator at one potential and a good conductor at a higher potential; hence its valve effect during and after the passage of a high voltage surge.

The Crystal Valve arrester consists of a porcelain casing enclosing the special discharge material Crystallite and a number of spark-gap electrodes in series therewith. The lower end of the porcelain casing is closed by the earth connexion and the upper end carries a porcelain cap which is sealed against the ingress of moisture and renders the unit weatherproof. The Crystallite also possesses a valve action somewhat similar to Thyrite. *See* Arrester, Lightning; Line Choking Coil; Reactor.

SUSCEPTANCE. The rule for circuits in parallel may be stated in similar form to that for circuits in series, by introducing a quantity known as admittance (*q.v.*), equivalent to the reciprocal of impedance; the total admittance then equals the vector sum of the separate admittances. Then, in a similar way to that in which impedance may be split up into two components at right angles consisting of

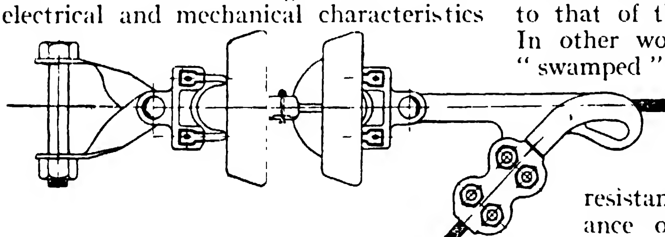
the resistance and reactance respectively admittance may also be resolved into two components known as conductance and susceptance respectively. The rule for circuits in parallel then becomes

admittance $= \sqrt{(\text{Sum of conductances})^2 + (\text{Sum of susceptances})^2}$.

Susceptance is therefore that component of the admittance which when multiplied by the E.M.F. gives the wattless component of the current in a circuit. It equals the reactance divided by the sum of the squares of the resistance and the reactance. *See* Admittance; Conductance; Impedance; Reactance; Resistance, *etc.*

SUSCEPTIBILITY (Magnetic). The ratio of the intensity of magnetization in a sample of iron to the magnetic force producing it. This quantity is usually represented by the Greek symbol κ For ferro- and paramagnetic substances it has a positive value, for air it is zero, and for diamagnetic materials it is negative. *See* Permeability.

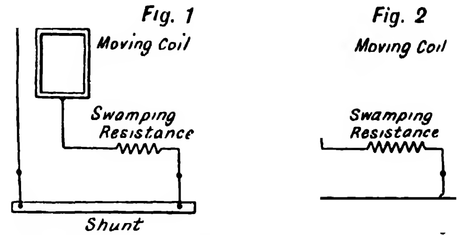
SUSPENSION OR STRAIN INSULATOR. Pin insulators (*q.v.*) are widely adopted abroad for voltages up to 66 kV. Above this value they are more expensive to construct than suspension insulators, and even for lower voltages the better electrical and mechanical characteristics



SUSPENSION INSULATOR. Fig 1 A disc strain insulator for making a joint between a live wire and an uninsulated wire under mechanical tension

Allen West & Co., Ltd

of the latter more than compensate for any slight increase in cost. The suspension insulator is therefore used on most sections of the "Grid" and in fact in most modern transmission lines. Their great advantage is the facility with which they can be built up in a number of units to suit the line voltage in question. The two types chiefly used are the Hewlett interlinked fitting, also known as the link insulator, and the metal hood type with fittings cemented to the insulator. The flux distribution is improved in the latter for equal mechanical strength, but slight increase in cost. Owing to shunt and



SWAMPING RESISTANCE. Fig. 1. Moving-coil ammeter with swamping resistance. Fig. 2. Moving-coil voltmeter with swamping resistance.

series capacity effects, a string of suspension discs has a lower flash-over voltage than the sum of the separate flash-over voltages for each disc. *See also* Pin-type Insulator; Porcelain Insulator.

SWAMPING RESISTANCE. Swamping resistance is the name given to the non-inductive stationary resistance which is placed in series with an ammeter or a voltmeter in order to render the instrument as insensitive as possible to temperature errors. Figs. 1 and 2 show the connexions for a moving-coil ammeter and voltmeter respectively. The resistance consists simply of wire of manganin, constantan, or some similar alloy wound non-inductively upon a frame or spool and proportioned so that its total resistance is very high compared to that of the instrument moving coil. In other words, the coil resistance is "swamped" by that of the auxiliary resistance. The alloys used have a high specific resistance and a low temperature coefficient of resistance, and hence the resistance of the moving coil of the instrument is swamped and tem-

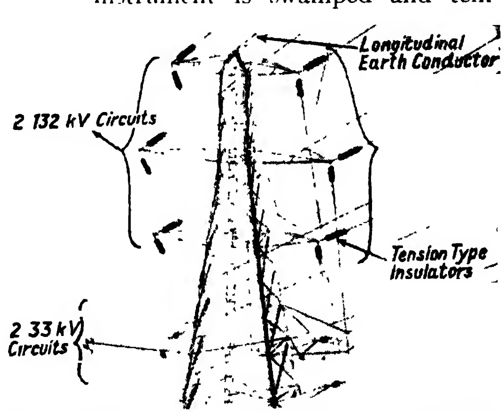
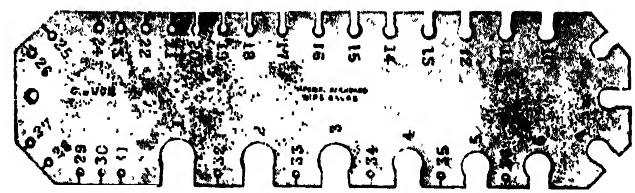


Fig. 2. Suspension insulators on a 132-kV. transmission line of the steel pylon type.

Callender's Cable & Construction Co., Ltd.

perature errors are minimized. *See* Temperature Effects (in Instruments).

S.W.G. This is the abbreviation commonly adopted for the British standard wire gauge (*q.v.*), the only legal standard wire gauge in the United Kingdom and fully discussed in this work under its own heading.



S.W.G An imperial standard flat wire gauge used for measuring the thickness of sheet metal from 7 6 mils to 300 mils. Mil is the standard abbreviation for one thousandth of an inch.

The photograph shows the usual imperial standard wire gauge tool for finding thicknesses of metal or diameters of wires from 36 gauge to 1 gauge, *i.e.* from ·0076 of an inch to ·3 of an inch in thickness. This gauge is extremely useful to all practical electricians. *See also* Gauge.

SWITCHES OF ALL KINDS

By Herbert Wright, M.Sc. (Eng.)

Any device for closing or opening a circuit is a switch, but here we are concerned mainly with low voltage and small power switches, a large number of which now in general use are described here in alphabetical order. Circuit Breakers, both air and oil, are described under that heading. See also Contactor; Dead Hinge Switch; Home Office Regulations; Knife Switch; Switch Fuse; and other headings indicated in the following pages by cross references. Switchgear in power work and Switchboards are the subjects of important main articles following the present.

A switch is a device for cutting off or establishing the flow of current by providing alternative insulating or conducting material between two points in a circuit. The insulating material is usually air in small switches, and oil in larger ones and on high voltage circuits. The insulating gap is bridged by a metallic conducting strip when current is to flow. The following points are important in the performance of switches.

Contacts. The contacts must be of large enough cross-section to carry the rated current without overheating, and the area of contact between the fixed and moving parts of the circuit-making device must be sufficiently large to avoid heating. The pressure between the fixed and moving parts of the contact must be sufficient to hold the two well together, but must not be so great as to render opening and closing difficult. In order to keep the contacts clean and so keep the contact resistance low, the moving contact is made to rub or " wipe " over the fixed contact.

Length of Gap. The length of the insulating gap between the fixed and moving contacts must be long enough to prevent an arc being drawn out and persisting when the circuit is broken.

Rate of Make and Break. The rate at which the contacts bed in must be quick enough to prevent heating and local arcing and burning due to the small area in contact as the two just touch. When the circuit is broken, the rate at which the contacts move apart must be high enough to break the arc drawn out at parting before it has time to burn the contacts. In some cases, an additional contact, called the " arcing contact," is provided in parallel with the main contacts. The arcing contact makes circuit before and breaks after the main contact, so that all arcing and burning at the main contacts is obviated· while, as it is very light in weight, the arcing contact can be made to travel quickly.

Mechanical Action. On quick-break switches, the movement is always produced by a spring, and those which have a quick-make action as well are operated through a spring-actuated toggle. The construction of the switch as a whole must be sufficiently robust to withstand the mechanical shock produced when the moving parts are suddenly brought to rest at the end of the opening travel.

Types of Contact. The different methods of bringing together the surfaces of the contacts can be broadly classified thus:

(i) A flat blade between two jaws giving side contact, as in a knife switch.

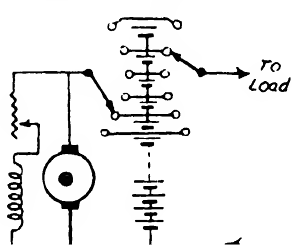
(ii) A butt contact between a laminated brush and a flat plate.

(iii) A plug and socket contact in which the socket is split and is pulled radially inwards on the round plug by springs.
(iv) A multiple point or line contact as used in push-button switches of the "emergency" type.
(v) A laminated brush sliding over a number of different contacts as in the accumulator switch.

General Details. The insulating materials used in the construction of the switch must be mechanically strong, while this and the clearances between contacts and between contacts and enclosing case must provide sufficient insulation to prevent flash-overs when metallic vapour is produced by the arc as the switch opens. The metal case of larger switches should be lined with insulating and fireproof material to prevent arcs striking to the case, and barriers of similar material should be placed between the sections of double and triple pole switches.

VARIETIES OF SWITCHES

ACCUMULATOR SWITCH. A secondary battery is often used in parallel with a generator, so that during periods of light load the generator charges the battery, and during heavy load periods the two work in parallel. As the voltage of a cell varies from 1·8 volts to nearly 2·7 volts, the voltage of a battery varies by a proportional amount, *e.g.* a 100-cell battery would change from 180 to 270 volts, on a nominal 200-volt circuit, depending on whether the battery was discharged or fully charged. Arrangements are therefore made to vary the number of cells in use by cutting out or inserting some of the end cells of the battery. This operation is performed by means of an accumulator switch, or, as it is often known, a regulating switch.



SWITCH Fig. 1. Connexions of battery and generator, showing tapping switches on end cells.

The switch consists of a rotating arm moving over a series of contact segments, between each two of which a cell is connected. As the number of cells in circuit

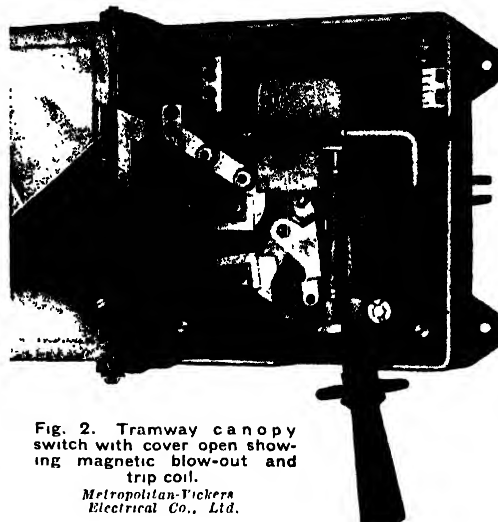


Fig. 2. Tramway canopy switch with cover open showing magnetic blow-out and trip coil.
Metropolitan-Vickers Electrical Co., Ltd.

may have to be changed while on load, and therefore no interruption in the supply can be allowed, the rotating contact arm is split into two halves, between which a resistance is connected. If the arm were solid it would short-circuit adjacent cells as it was rotated, and the only way of avoiding this would be to put in dummy segments, but this would cause an interruption in the circuit. The resistance prevents excessive current flowing when the two cells are joined, while it has no effect on the main circuit.

AIR-BLAST SWITCH. This term is used to describe a high voltage switch in which compressed air is used to extinguish the arc formed on breaking circuit.

AIR-BREAK SWITCH. When air, as distinct from oil, is used to insulate the gap formed when the switch is opened, the switch is distinguished in this way. *See* Circuit Breaker (Air) *and* Horn Arrester.

ASYLUM SWITCH. A switch in a branch circuit provided with a locked cover. The name is also given to a form of tumbler switch in which the operating knob is replaced by a detachable key.

AUXILIARY SWITCH. A switch mechanically coupled to a circuit breaker for operating indicating devices or some auxiliary piece of apparatus.

BATTERY SWITCH. *See* Accumulator Switch, *above.*

BREAKDOWN SWITCH. In three-wire systems fed from two mechanically coupled generators, a switch is sometimes provided to couple together the two

" outer " conductors, should this be necessary due to a breakdown on one generator.

BUS-BAR SWITCH. *See* Sectionalizing Switch, *below*.

BY-PASS SWITCH. A switch provided to be connected in parallel with a large circuit breaker, so that the supply can be maintained when the breaker is withdrawn.

CANOPY SWITCH. A main switch fixed on the roof above the platform on tramcars. It is fitted with an overload trip and a blow-out coil, *i.e.* it is a circuit breaker.

CEILING SWITCH. On lighting circuits local lighting points are sometimes controlled by a switch fixed on the ceiling adjacent to the ceiling rose. The switch is operated by pulling a cord, alternate pulls switching on and off.

CHANGE-OVER SWITCH. A switch used for providing alternative connexions, *e.g.* in some three-wire systems the lighting is sectionalized, and the load is balanced by changing over sections from one side of the mains to the other.

COUPLED SWITCH. Two or three separate switches coupled mechanically by a bar so that all are operated together. A double-pole switching arrangement of this type is usually provided for the main switch on house-lighting circuits, by coupling together two single-pole tumbler switches. Switches can also be mechanically interlocked in this way, so that when some are on others are off.

DIAL SWITCH. A rotating multiple contact switch with the segments arranged round the whole circumference of a circle, so that the rotating arm connects the segment to a concentric ring. By using more than one arm and ring, several contacts can be varied at once, and this type of switch is much used on high-grade potentiometers (for voltage measurement) and decade resistance boxes.

DETACHABLE KEY SWITCH. *See under* Asylum Switch, *above*.

DISCONNECTING SWITCH. *See* Isolating Switch, *below*; *also* page 379.

DOUBLE-BREAK SWITCH. In order to save room in switches for use on larger current ratings and on higher voltage circuits, it is the practice to put two breaks in series in the same part of the circuit. For the same movement of the switch blade, up to twice the length of gap can be obtained. Knife switches are usually provided with a double break to avoid having the current passing into the blade through the hinge pin (*see* Dead Hinge Switch).

DOUBLE-POLE SWITCH. A switch made to make and break a supply on both sides of the circuit at once, by means of two similar switches mechanically coupled,

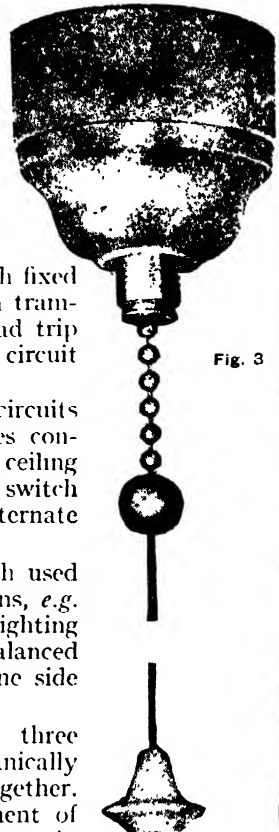


Fig. 3

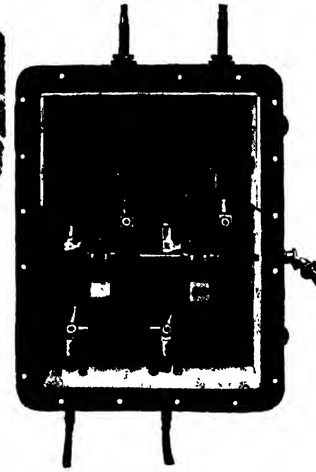


Fig. 4.

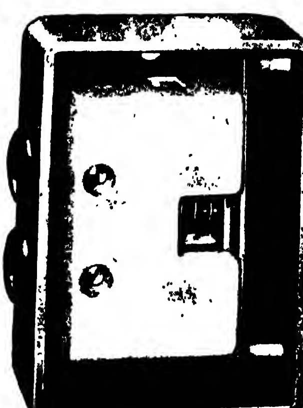


Fig. 5.

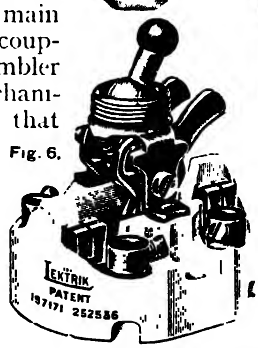


Fig. 6.

SWITCH. Fig. 3 "Crabtree" 5-amp. flat ceiling switch. Fig. 4. Whipp & Bourne mining control switch. Fig 5 G.E.C. door bolt switch. Fig. 6. Lundberg double-pole tumbler switch.

e.g. in a D.C. circuit one side of the switch would be in the positive main and the other in the negative. (Abbreviation D.P. Switch.) *See* Double Pole.

DOUBLE-THROW SWITCH. This is a switch for providing alternative connexions by having two sets of fixed contacts, one set being on each side of the switch pivot. When the switch is "thrown in" on one side one set of connexions is obtained, the alternative connexion being made by throwing the switch over to the other contacts. Such a switch would be used for connecting a load to alternative sources of supply, or for giving the "start" and "run" positions on an induction motor starter. (Abbreviations: D.T. Switch; D.P.D.T., Double-Pole Double-Throw.) *See* Change-over Switch, *above*.

EARTHED SWITCH. The name given to a switch which has all metal parts, other than those actually connecting the circuit, connected to earth.

ELECTRO-MAGNETIC SWITCH. Any switch (usually a circuit breaker) operated by a current flowing in a solenoid in such a way that the action of the solenoid on the armature closes the switch. Opening of the switch is performed by switching off the solenoid current, the switch either dropping out under gravity or being opened by a spring. *See* Contactor.

ELECTRO-PNEUMATIC SWITCH. A switch operated by the action of air on a piston, the air being admitted to the operating cylinder by an electro-magnetically operated valve. This type of switch is much used in the control gear on trains.

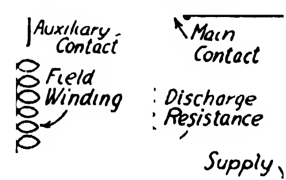
ELECTRO-SYNTONIC SWITCH. A small switch which is operated by a tuned reed, the reed being set in vibration by a current of one frequency only. It is used in signalling and remote control systems, the operating current being carried along the same lines as the power current or other signalling current.

EMERGENCY SWITCH. Where a motor is used to drive groups of machines spread over a fairly large area, it is customary to provide at different points among the machines a switch of the push-button type which when pressed will stop the motor in case of emergency. It usually operates by short-circuiting the no-volts coil. Other instances of use are on escalators, large printing presses, planing machines and rolling mills, and in some high-voltage installations.

EQUALIZER SWITCH. When compound generators or rotaries are run in parallel, load sharing is obtained by means of an equalizing bus-bar. The equalizing switch is that one which connects the machine to this bus-bar. *See* Equalizing Bar.

FEELER SWITCH. In some automatic substation systems a switch is provided to test out the circuit after a circuit breaker has tripped out (due to a short circuit, for instance). This feeler switch is electrically interlocked with the circuit breaker in such a way that the latter is held out until the circuit is clear.

FIELD SWITCH. The field winding of a large machine has a very high value of inductance. If a current flowing in it were suddenly stopped a very high voltage would be induced in the winding, and would tend to break down the insulation. This is avoided by connecting a field discharge resistance across the winding, the energy



SWITCH. Fig. 7. Field switch circuit. As main contact opens, auxiliary closes and connects field to discharge resistance.

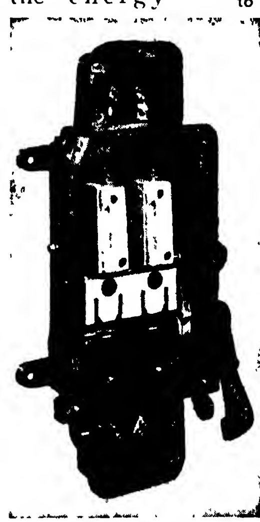


Fig. 8

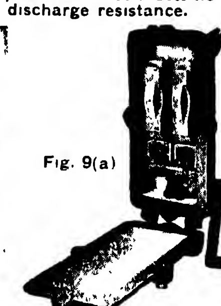


Fig. 9(a)

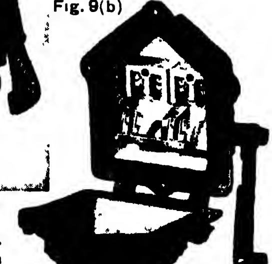
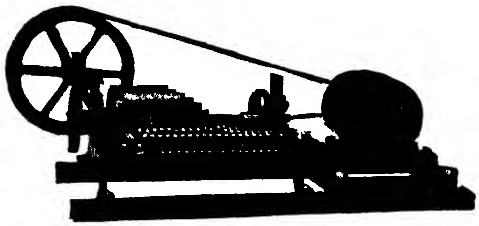


Fig. 9(b)

Fig. 8. A G.E.C. flame-proof ironclad switch and fuse for industrial and colliery use. Fig. 9 (a). "Warwick" flame-proof switch with fuses; (b) switch alone.
G. E. C. and Wm. McGeoch, Ltd.



SWITCH. Fig. 10. Flasher switch motor driven for animating electric signs.
General Electric Co., Ltd., of England

in the field magnet being dissipated in this resistance. In order to avoid waste of energy, the resistance is only connected when the switch is being opened. To do this an auxiliary contact is fitted to the main switch, and this contact connects the field winding to the resistance an instant before the main circuit is broken

FLUSH SWITCH. A switch, used on lighting circuits, which is placed in a recess in the wall so that only the " dolly " protrudes, the whole being covered by a flat plate fitting close to the wall. The switch is the same in action as a tumbler switch, and is fixed in a wooden or an iron box let into the wall.

FOOT SWITCH. Where an electrically operated machine requires the use of two hands, *e.g.* a sewing machine or a welding machine, a foot-operated switch is used.

FUSE SWITCH. A switch with fuses situated in the same housing. In some cases the fuse is used as the moving link of the switch. *See* Switch-fuse, *and* Fuses and Fusing Systems.

GANG SWITCH. Two or more switches, controlling separate circuits coupled together mechanically so that all are operated together, *e.g.* in stage lighting

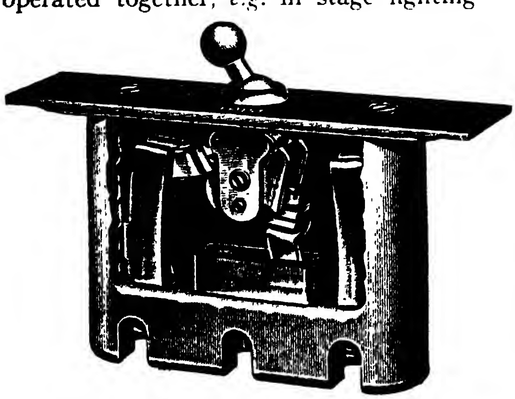


Fig. 11. " Klymax " flush panel switch.
A. P. Lundberg & Sons.

HOME OFFICE SWITCH. A switch conforming to Home Office Electricity Regulations in that it is made shock-proof by being earthed.

HORN-BREAK SWITCH. High voltage air-break switches have horns attached to the contacts. These horns make and break the circuit, so avoiding arcing at the main contacts. *See* Horn Arrester.

HOSPITAL SWITCH. A switch fitted on tram or train controllers, its function being

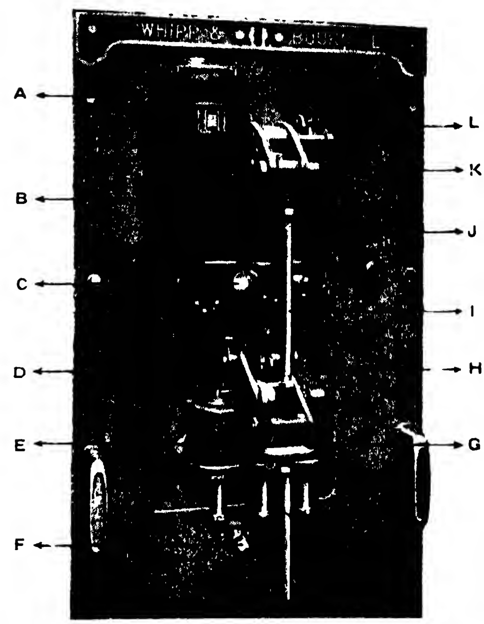


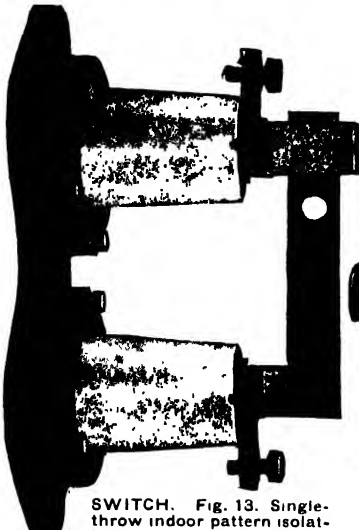
Fig 12. Enlarged view of hydraulic-electric oil breaker with operating and repeater reclosing mechanism. A is mains-operated motor ; B, transmission chamber ; C, resetting time control valve ; D, oil breaker lever closing mechanism ; E, overload trip coil casing ; F, shaft of tank lowering gear ; G, auxiliary handle for manual operation of oil breaker ; H, easy trip release ; I, oil breaker operating rod ; J, oil ram cylinder ; K, counter ; L, auto-repeater reclosing device.
Whipp & Bourne, Ltd

to cut out a motor when this develops a defect by putting it out of service. In this way a vehicle is enabled to proceed on the remaining serviceable motors to the depot.

INTERLOCKING SWITCH. *See* Interlocking (Electrical).

INTERMEDIATE SWITCH. A switch used for providing three-point control of landing lights, etc. It is a reversing switch (without an " off " position) and is used with two two-way switches (*q.v.*). It operates by reversing the connexions between the two two-way switches.

ISOLATING SWITCH. A switch of the knife pattern used as an isolating link.



SWITCH. Fig. 13. Single-throw indoor pattern isolating switch, 100-1000 amps, 660 11,000 volts
Whipp & Bourne, Ltd.

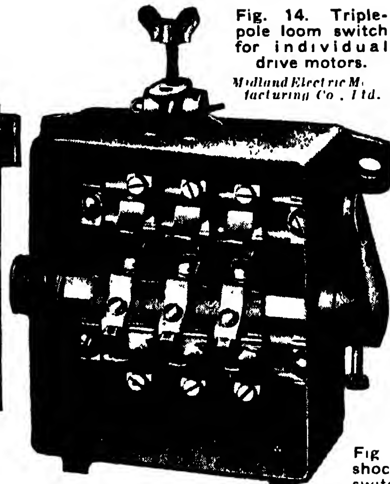


Fig. 14. Triple-pole loom switch for individual drive motors.
Midland Electric Manufacturing Co., Ltd.

Fig 16. "Crabtree" shock-proof pear switch; note wiring facilities and action.

Fig. 15. Machine switch to carry 4 amps at 500 volts.
J. P. Lundberg & Sons

KEY SWITCH. A switch usually combined with a lamp holder, being operated by turning a small flat handle in a similar manner to turning a key

KNIFE SWITCH. *See* Knife Switch.

LAMINATED BRUSH SWITCH. A switch of the butt contact type in which the moving contact is made up of a number of thin strips, each free at the contact end to be l into the fixed contact individually

LIMIT SWITCH *See* Limit Switch

LINKED SWITCHES Coupled switches (*see above*) or switches arranged to close in a definite sequence by being coupled mechanically.

LOCKED COVER OR LOCKING SWITCH *See* Asylum Switch, *above*

MAIN LIMIT SWITCH. A limit switch (*q.v.*) which is connected in the main power circuit, either directly or through a relay

MASTER SWITCH A switch used to control a number of lighting points which are also controlled by local switches. Alternatively, it may be a switch used to control a number of switches in other circuits by means of relays or contactors *See under* Master Switch

MERCURY SWITCH. One in which the fixed contacts are cups of mercury, as in some forms of battery cut-out. Another form consists of a sealed glass tube in which a pool of mercury bridges two contacts when the tube is tilted by a relay, etc. Used on thermostats.

MOTOR-OPERATED SWITCH A switch closed by a motor, as distinct from a solenoid-operated switch. This method is used mainly on large oil circuit breakers which are remote-controlled.

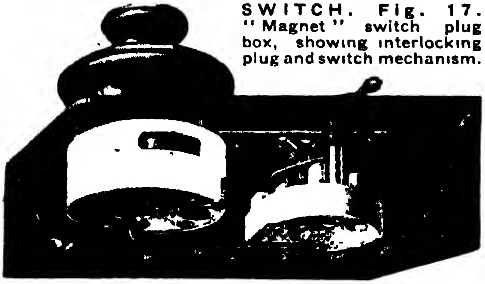
MULTI-BREAK SWITCH. A switch provided with a number of fixed and moving contacts in series to give a number of gaps in series when the switch is opened.

MULTIPLE-CONTACT SWITCH. One in which a moving contact, usually arranged to rotate, can connect to alternative fixed contacts, as would be used for tapping a regulating resistance.

MULTI-WAY SWITCH. A multiple contact switch used for connecting to different circuits, *e.g.* as would be used for connecting one instrument to a number of different points at which measurements are required.

OIL OR OIL-BREAK SWITCH. A switch immersed in oil. *See* Circuit Breaker; Oil.

ONE-WAY SWITCH. A switch which can only be used for making and breaking a



SWITCH. Fig. 17. "Magnet" switch plug box, showing interlocking plug and switch mechanism.

circuit, and not for providing alternative connexions. *Compare* Two-way, Three-way, and Multi-way Switch.

PANEL SWITCH. *See* Flush Fittings

PEAR SWITCH. A name used for a pendant switch, so called because it is pear-shaped: it is usually operated by pushing on a projecting bar.

PENDANT SWITCH. A switch suspended from the ceiling by a flexible cord which forms the leads to the switch. They are used for controlling local lighting points and extensively for giving two-way control of bedroom lights. *See* Pear Switch; Pressel Switch.

PLUG-SWITCH. This closes a circuit by the insertion of a plug, usually conical, which bridges the gap between two insulated fixed contacts. Used only on low-voltage circuits and on instruments, etc., for altering the range. *See* Plug.

PLUNGER SWITCH. *See* (iii) under Types of Contact at the beginning of the present article.

PNEUMATICALLY OPERATED SWITCH. A switch operated by compressed air. *Cf* Electro-pneumatic Switch.

POLE SWITCH. A switch mounted on an overhead line pole, and operated from ground level by a long cane pole with a hook or ring.

POLE-CHANGING SWITCH. A switch used for changing the number of poles produced by the winding of an induction motor, and so changing its speed. *See* Control of Motors.

PRESSEL SWITCH. A pendant switch operated by pressure on a projecting button.

PULL SWITCH. *See* Ceiling Switch, *above.*

PUSH-BUTTON SWITCH. *See* Push-Button Control.

QUICK-BREAK. The name given to a switch in which the break is quick and independent of the rate at which the switch is operated. *See page* 1188.

RECESSED SWITCH. *See* Flush Fittings.

REGULATING SWITCH. Any multiple contact switch for regulating the speed, voltage, etc., of a machine or for regulating the flow of current in a circuit. Also used as an alternative name for accumulator switch (*see above*).

REMOTE-CONTROL SWITCH. *See* Remote Control.

REVERSING SWITCH. One used for reversing the direction of flow of current, or for reversing the direction of rotation or polarity of a machine, either by reversing current direction or otherwise.

ROTARY SWITCH. The term used to describe a small switch operated by rotating the switch knob in one direction only for both the "off" and "on" positions. *Compare* Turn Switch.

SECTIONALIZING SWITCH. When a number of machines or transformers are used to supply feeders, the feeders may be grouped into sections, with one supply unit to each section. During periods of heavier load, or when faults develop, the sections are isolated from one another, but during light-load periods, the sections are grouped so that one machine or transformer will supply all. On low voltage systems, the switches are often of the

Fig.

Fig. 19. "Mem 8" quick-break all-insulated combination switch and fuse.

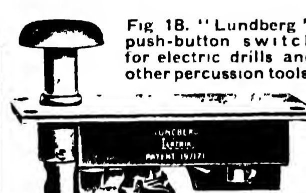


Fig 18. "Lundberg" push-button switch for electric drills and other percussion tools.

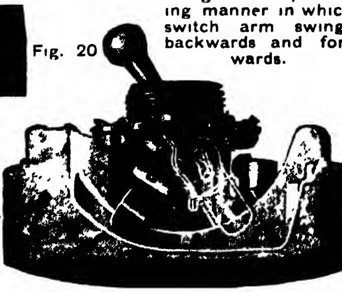


Fig. 20

Fig. 20. Section of a Crabtree "Underslung" switch, showing manner in which switch arm swings backwards and forwards.

multiple blade knife pattern, and are fitted with clamping screws to reduce contact losses. Such switches are not intended to break a large amount of power.

SELECTING SWITCH. Switch used in automatic lift control systems for selecting the floor at which the lift is to stop.

SELECTOR SWITCH. A switch used for connecting, either automatically or otherwise, to one of a number of circuits.

SEMI-RECESSED SWITCH. A small switch of the tumbler pattern, the base of which is sunk in the wall, but has the domed cover projecting.

SEQUENCE SWITCH. This is used to close circuits in a definite order, either directly or through relays and interlocks. *See* Remote Control.

SERIES-PARALLEL SWITCH. A switch, usually a double-pole double-throw, used for changing the connexions of two pieces of apparatus from series to parallel, *e.g.* when used with two lamps would give "bright" and "dim" in the parallel and series positions respectively.

SHOCK-PROOF SWITCH. One in which all external parts are of insulating material, often strengthened by shrouding metal with insulation.

SINGLE-BREAK SWITCH. A switch with only a single gap when it is open. *Cf.* Multi-Break Switch.

SINGLE-POLE SWITCH. The name given to a switch operating in one side of a circuit only, *e.g.* in one main only. *Cf.* Double-Pole and Triple-Pole Switch.

SINGLE-THROW SWITCH. A switch with only one set of fixed contacts so that it only closes the circuit in one position, *i.e.* a one-way switch (*q.v.*).

SINGLE-WAY SWITCH. *See* One-Way Switch, *above*.

SLOW-BREAK SWITCH. One in which no provision is made to separate the contacts quickly. Sometimes used on inductive circuits. *Cf.* Quick-Break Switch.

SNAP SWITCH. A less common name for small switches of the tumbler type (*q.v.*) provided with a quick-make and quick-break action, as used on branch lighting circuits.

SOLENOID SWITCH. A form of electromagnetic switch, in which the armature is a plunger sucked into the solenoid when this is energized. *See* Solenoid.

SPRING SWITCH. In some instances a switch is required to make contact for a few seconds at a time. For such a purpose the switch only remains closed while the operating lever is depressed, a spring being used to hold the switch in the open position. One application is for controlling the heater circuit for striking the arc in "Pointolite" lamps, while they are sometimes used in the starting circuit of small single-phase induction motors.

STEP SWITCH. *See* Multiple-Contact Switch, *above*.

SUNK SWITCH. *See* Flush Switch, *above*.

TAPPET SWITCH. A switch operated by being struck by a tappet during the course of movement of some mechanism driven electrically, the switch being used to control the movement. For example, large planing machines have the move-

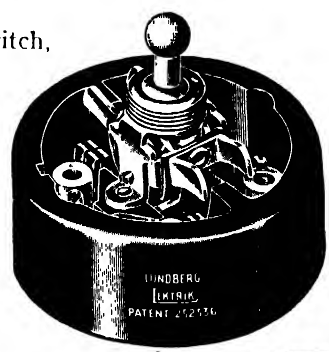


Fig. 21

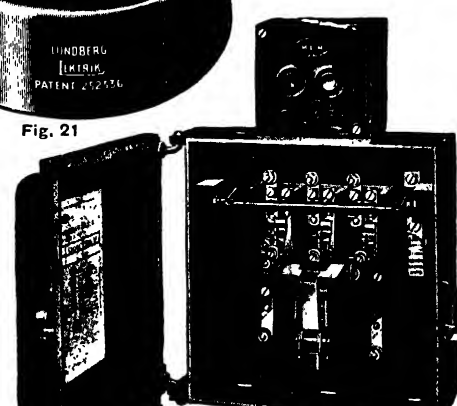


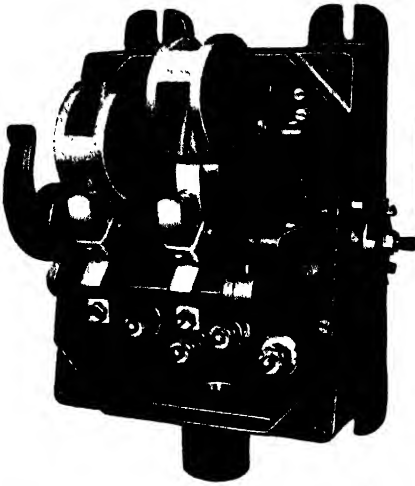
Fig. 22

SWITCH. Fig. 21. "Lundberg" series-parallel 5-amp. surface-pattern switch. Fig. 22. "Auto-Memota" starting switch operated by push button.

ment of the table reversed by a tappet switch reversing the driving motor, the length of travel of the table being varied by altering the position of the tappets attached to the bed. Many limit switches (*q.v.*) are of this type.

TELEPHONE SWITCH. Usually of the jack and plug type. The term is sometimes employed to denote the whole switchboard.

TEMPERATURE SWITCH. A control circuit switch operated by temperature



SWITCH. Fig 23. Double-pole tappet switch with horse-shoe lever (cover removed)
Metropolitan-Vickers Electrical Co., Ltd

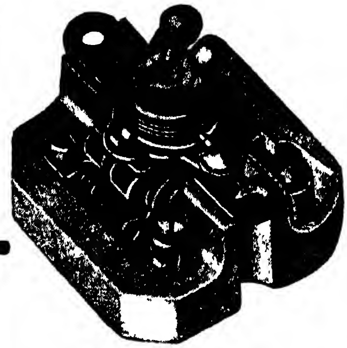


Fig 24 Crabtree "Binob" two-way switch taking the place of two separate one-way switches.

changes by means of thermostats. Used in automatic installations for protecting machines, etc., against sustained overload by shutting them down or bringing in other machines

THREE-POINT SWITCH. A three-way switch. The term is sometimes used to denote a switch with three contacts connected simultaneously, so that when the switch is off two of the circuits are not left in parallel. *Cf.* Three-Way Switch.

THREE-POLE SWITCH. *See* Triple-Pole Switch *below*; *also* under heading Three-Pole Switch.

THREE-WAY SWITCH A switch giving alternative connexion to any one of three independent circuits. *Cf* One-Way Switch; Two-Way Switch.

THROW-OVER SWITCH. A change-over switch of the "knife" pattern.

TIME SWITCH. A clock-operated switch used for opening or closing a circuit at fixed times. *See* Time Switch.

TRANSFORMER SWITCH. In one system of distribution from a transformer economies are effected on light loads by having a small and a large transformer, and automatically switching from one to the other by a "Transformer Switch" as the load varies

TRIP SWITCH. A switch used for tripping circuit breakers by closing the tripping circuit.

TRIPLE-POLE SWITCH. A switch of three single-pole units operated simultaneously, *e.g.* to open or close in the three branches of a three-wire circuit, either D.C. or A.C. (three-phase or two-phase). *Cf.* Single-Pole and Double-Pole Switch. *See* Three-Pole Switch.

TUMBLER SWITCH. A small switch operated by a short lever or "Dolly" and used extensively on low power lighting circuits for controlling the lamps. So called from the way the mechanism "tumbles" over the mid-position, so that it must definitely be "on" or "off." Obtainable in many varieties, chief among these being one-way, single- and double-pole; two-way, and two-way and off (Intermediate Switch, *q.v.*), single-pole; and three-way, single-pole

TURN SWITCH. A small switch operated by a rotatable knob, one direction of rotation switching on, and the other switching off.

TWO-POLE SWITCH. *See* Double-Pole Switch.

TWO-WAY SWITCH. A switch with two "on" positions, each making a connexion to a different circuit. Extensively used for giving two-point switching on branch lighting circuits. Compare Multi-Way-Switch, Three-Way Switch; One-Way Switch.

VACUUM SWITCH. A switch whose contacts operate in a highly evacuated chamber. To avoid any air-leakage due to glands, etc., the contacts are operated electro-magnetically. Alternatively, a switch operated by the production of a vacuum. Compare Pnuematic Switch.

Faults in Switches. The faults found in switches can be broadly divided into three classes: (a) bad contact, causing lights to flicker or a motor to run unsteadily; (b) overheating of the switch; and (c) burning of the contacts. Any one of these faults may produce the others. Bad contact may be caused through bad design of the switch in that excessive wear takes place on the hinge pins, throwing the contacts out of alinement, so that every time the switch is closed the fixed

contacts are pushed sideways. Overheating may draw the temper of the contacts so that they do not press together with sufficient force. These faults are common to cheap forms of switches.

Burning at the contacts may be due to bad design or the use of a switch not suited to the work it is called on to do. Some types of push-bar pendant switches have a comparatively slow make and break, so that if used for switching even a 60-watt lamp, the heavy current at switching on soon burns the contents.

It can safely be said that any switch of reputable make will perform satisfactorily the duties for which it is intended, but all switches of heavier current rating should have periodical cleaning and adjustment, with a thin smear of vaseline on the contacts to prevent them becoming dirty.

An aspect of switching often overlooked is that of safety from shock, and any switch placed in a damp situation should either be completely insulated or properly earthed. The former method is finding favour in domestic applications largely because the moulded insulation type of switch can now be produced more cheaply than any other, while all switches in industrial installations should conform to the Act dealing with factory installations, which requires all external metal parts of switches to be earthed.

SWITCHBOARDS FOR INDUSTRIAL AND OTHER USES

By S. Austen Stigant, M.I.E.E., F.Am.I.E.E., and C. J. O Garrard, M Sc.

This important section of the subject of power control is to be studied in conjunction with the article that follows, which is concerned with the principles, construction and uses of the controlling switchgear mounted on the switchboard. Here all varieties of boards, cubicles and gear for high and low tension A.C. circuits are described, with notes on care and maintenance. See also Circuit Breaker ; Power Station ; Remote Control ; Switchgear.

The types of switchboard which are in general use are flat-back boards, stone or brickwork cubicles, stationary cubicles, draw-out truck cubicles, the lighter-duty iron-clad boards (usually pedestal type) and the heavy-duty metal-clad gear.

Flat-back Switchboards. Switchboards carrying open type knife switches, fuses, etc., may have panels of slate, marble, or one of the manufactured materials available. Marble has good insulating properties, but is considerably more expensive than slate, and is easily stained by oil. Slate is mechanically stronger than marble, and has a good appearance when black enamelled and polished ; sand-rubbed oiled slate is cheaper than enamelled slate, and is suitable for most industrial situations. Carefully selected slate is almost equal to marble as regards insulating properties, but it is usual to insulate all panel fixing bolts and live stems which pass through the panels, with insulating bushes and washers as an additional precaution, and when extra high insulation resistance is required.

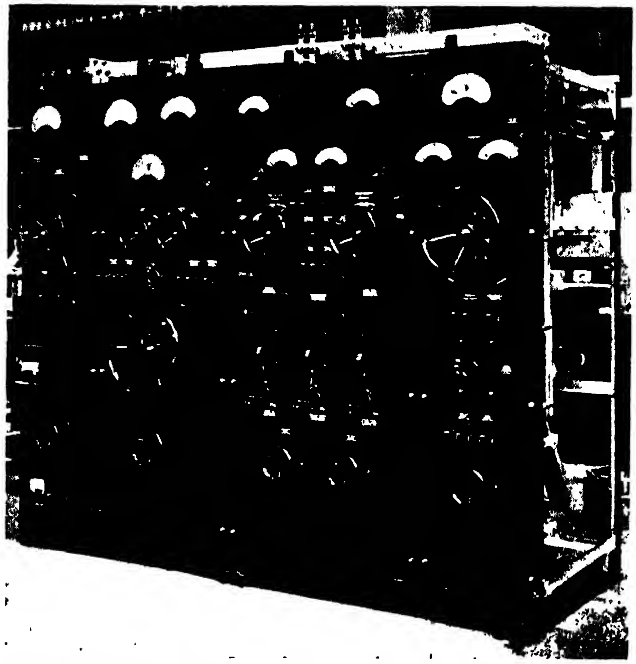
Slate should be dried out for about 36 hours at 100-120° C. Re-absorption of moisture may be prevented by oiling the slate after drying, or by enamelling all over, including all holes.

A good routine test for insulating properties is to place the slab on a metal table and explore the top surface with an electrode consisting of a $\frac{3}{8}$ inch diameter disc. After drying, unenamelled slate should give not less than 30 megohms when tested in this manner with a 500-volt megger.

Control boards and other switchboards which have only the live stems of instruments passing through the panels, may have panels of enamelled sheet steel plates, with either polished or dull black finish. On slate switchboards the bottom slabs often do not carry any apparatus, and expense can be saved by filling up with sheet steel plates of expanded metal.

The framework for supporting the panels is usually constructed either of angle and flat iron, or of pipe. Pipe framework has the disadvantage that all the weight of the panels and apparatus mounted thereon is taken by the panel bolts, which increases the strain on the panels and the risk of breakage.

Ample clearance should be allowed



SWITCHBOARD Fig 1. "Dead front" switchboard carrying the switchgear and measuring instruments of the electrical propelling machinery of a tugboat
General Electric Co., Ltd., of England

of the instruments and the operating handles of the switches appearing on the front, which is thus clear of live parts (Fig. 1). The panels in such cases are generally of steel, and are more robust than slate or marble boards: they have advantages where unskilled attendants may have to do with the switching. To the taste of many they present also a more attractive appearance than flat-back boards. Compared with flat-back boards, they are at a slight disadvantage inasmuch as the apparatus mounted behind the panel is more difficult of access for cleaning and inspection; their cost also is somewhat greater.

Cubicle Type Boards. When oil circuit breakers first began to be used instead of air-break switches it was customary to mount them behind flat-back boards, without any precaution being taken to separate them from the other apparatus. This is a very simple and cheap arrangement and is still used occasionally although the official regulations limit its use in this country.

The development of cubicle boards began when guards or shields were fitted between the oil circuit breakers and neighbouring apparatus. These consisted at first simply of slabs of insulating material fixed at right angles to the board. Later it became recognized that it was more effective to enclose all the apparatus belonging to one circuit in a separate cubicle, so that in the event of a breakdown the effects would be confined to the circuit in question. This construction has also the great advantage of protecting anyone engaged in cleaning or adjusting apparatus from accidental contact with live conductors in neighbouring circuits.

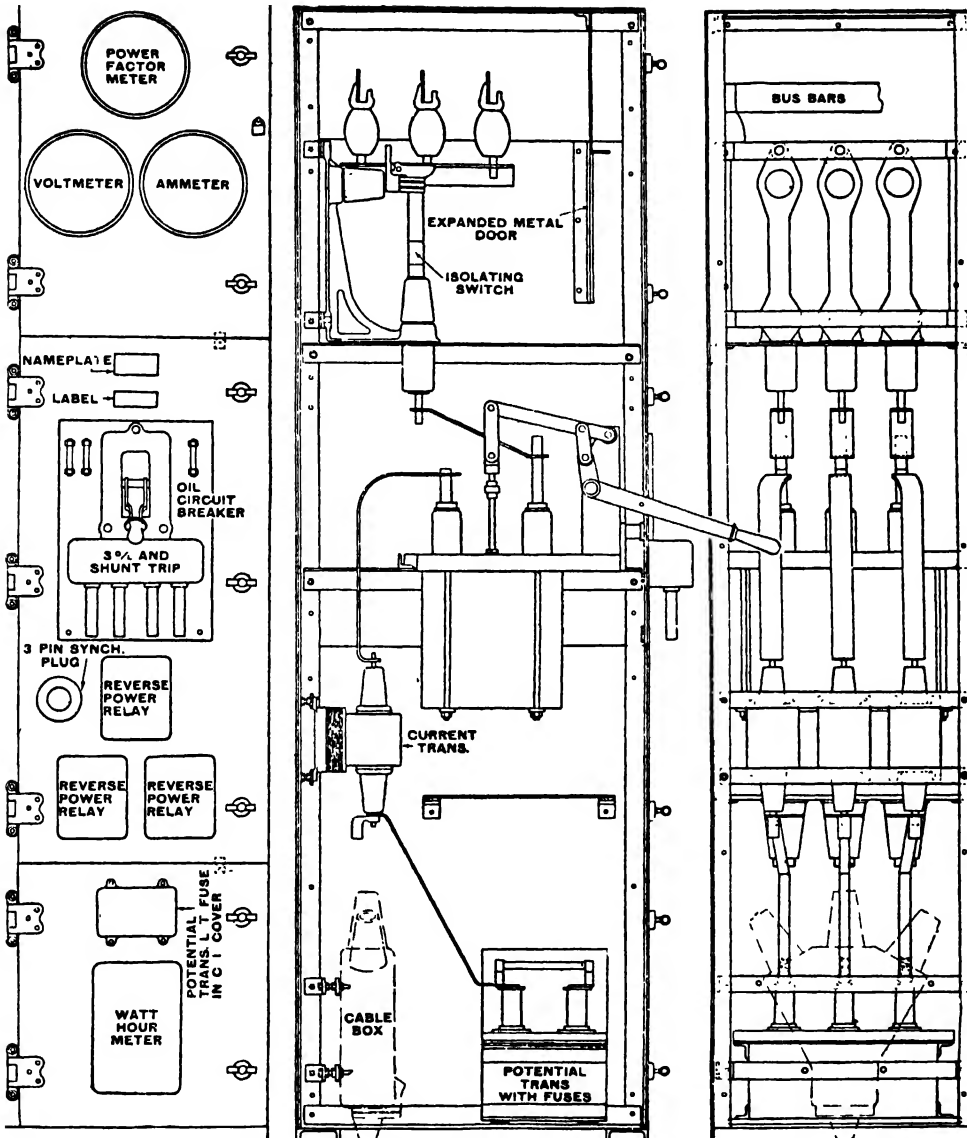
Ferranti carried this construction to its logical conclusion in introducing the "cellular" principle, where each piece of apparatus is in a separate cell.

Sheet steel plates, $\frac{1}{8}$ inch thick, are commonly used for cubicles, but very small cubicles may have thinner plates. The

between bare connexions for electrical requirements and also to facilitate cleaning and inspection. For bare connexions the minimum permissible clearance between poles or to earth is 1 inch for pressures up to 250 volts, and $1\frac{1}{2}$ inches for pressures of 251 to 660 volts. Where these clearances cannot be obtained, non-inflammable insulating barriers or other suitable insulation should be provided. Fig. 6 illustrates the back of a D.C. switchboard which has been designed on these lines.

Apparatus on the Panel. For low tension, oil switches are seldom used, and it is more convenient to use air circuit breakers (*q.v.*), which should be mounted on the top of the panel so that there is no risk to the attendant of burning by arcing at the contacts (Fig. 5).

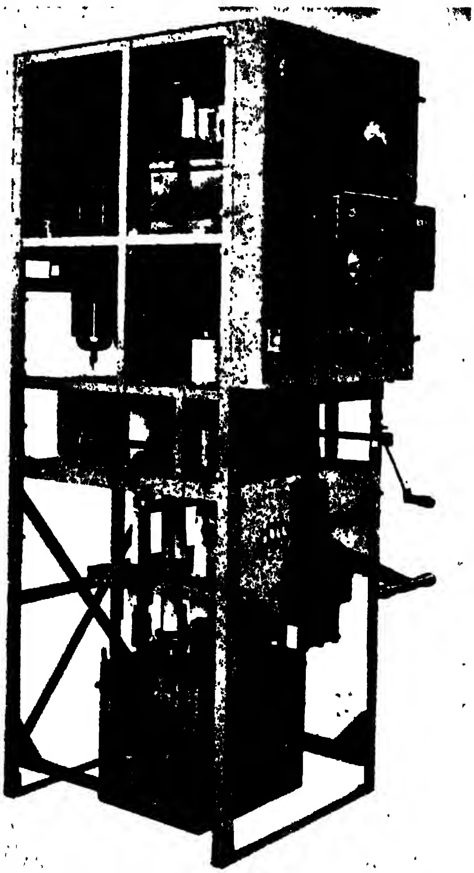
In Great Britain it is general practice to mount the switches and circuit breakers on the front of the panel, leaving the back clear for bus-bars and connexions (Fig. 8). On the Continent, however, the "dead front" type of board meets with more favour. In this all the apparatus is mounted behind the panel, only the faces



SWITCHBOARD. Fig. 2 Typical arrangement of H.T. steel plate cubicle with front access; for direct manual operation.

plates should be hydraulically flattened, and every care taken to obtain accurately squared corners, so that doors and covers will fit flush and without leaving gaps.

Cubicle Boards for Industrial Applications. These boards, which are usually constructed for voltages up to about 11,000, can be shipped completely assembled and then need little work on site (Fig. 2). The fronts of the cubicles, which may be set side by side in a row, constitute the panel and access may be from the front or rear; if instruments are mounted on the panel, rear access is more convenient as the necessity of arranging the front of the cubicle as a door and accordingly of supplying flexible connexions to the instruments disappears. On the other hand, space can often be saved by setting the backs of the cubicles against a wall and having access to them by doors in front (Fig. 7 on Plate facing page 1200).



SWITCHBOARD Fig. 3 Unit of steel cubicle switchboard in which the circuit breakers are isolated from the bus-bars by being lowered. One of the current transformers is visible at the rear and the potential transformer with its protective fuses in the top of the cubicle Fig. 4 (below) General arrangement of truck-type switchboard.

General Electric Co., Ltd., of England

It is customary, particularly where the boards are to be attended by unskilled labour, to subdivide the doors and interlock them with the circuit-breaker and isolating links so that the door giving access to the circuit-breaker cannot be opened unless the isolating links are open, and also that the isolating links cannot be closed when the circuit breaker door is open (Fig. 7 on Plate). The circuit breaker is also interlocked with the isolating links so that these cannot be either opened or closed unless the circuit breaker is opened. The circuit can thus neither be made nor broken with the isolating links.

Such simple cubicle boards are usually made for hand operation, the handles of the breakers passing through the panel.

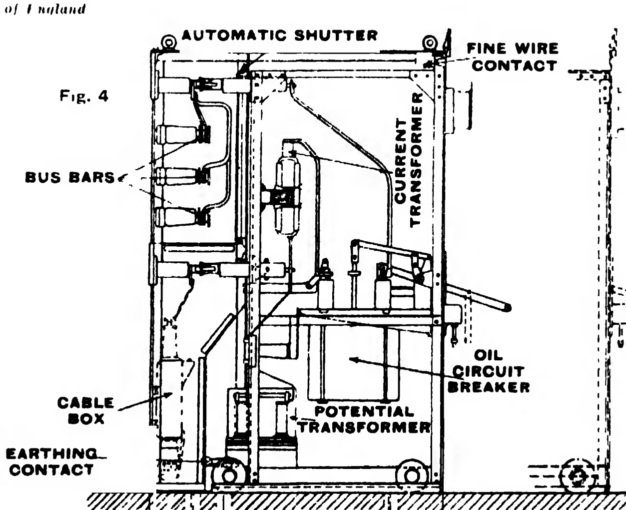
A development of the ordinary cubicle board which is used where space is limited is that in which the circuit breaker is isolated from the bus-bars by being dropped down (Fig. 3).

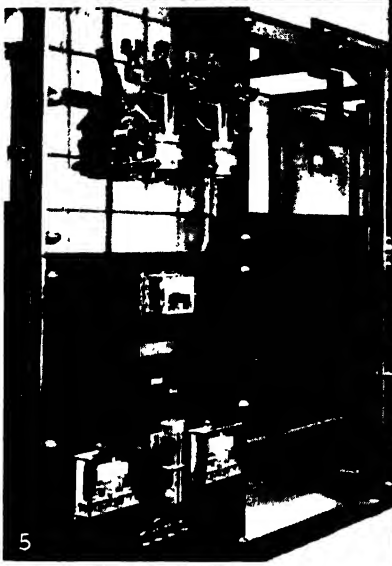
The kiosks used for distribution transformers in residential districts are also a form of cubicle board.

Cubicles can usually be arranged for front access only, thus saving the space required for a passage-way behind a board, but if space permits, it is always an advantage to arrange for doors both back and front to facilitate the work of cleaning and inspection. Cubicles should be designed so that any item of equipment can be removed without dismantling other apparatus.

Truck Type Board. This is a development of the steel cubicle board. The circuit breaker, current and potential transformers, fuses, etc., are all mounted on a kind of vertical truck, the front of which forms the panel. Only the bus-bars are mounted on the fixed part of the board. Contacts on the rear of the truck engage with corresponding contacts on the bus-bars, when the truck is pushed into its cubicle.

Fig. 4





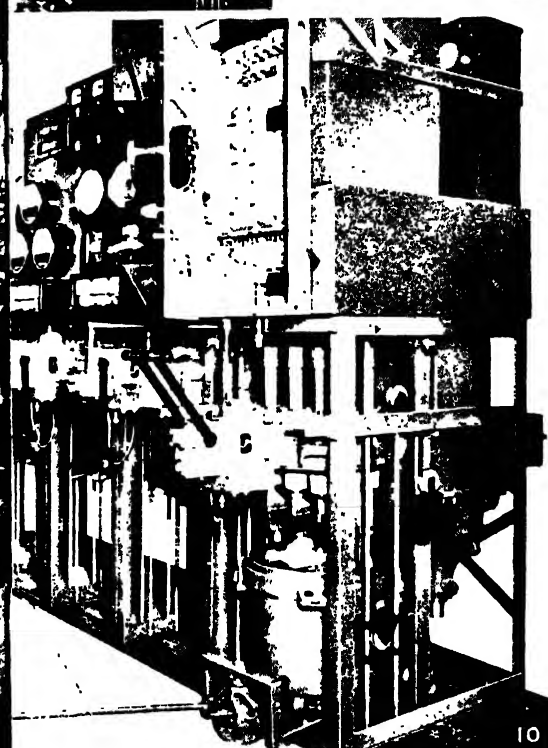
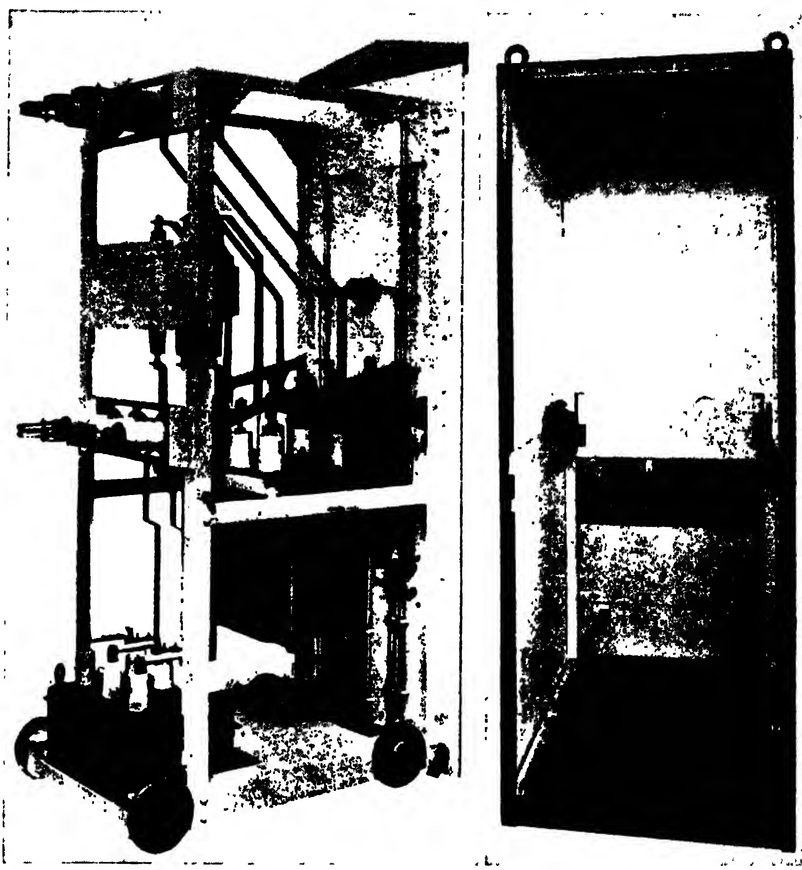


Fig. 5. " Flat-back " switchboard, 460 vol ·w of " flat-back " D.C switchboard Fig 7 Steel plate cubicle
showing interlocking between the doors, th iring clearly shown Fig 9. Steel plate cubicle board with front
access. The isolati -kV 3-phase supply from the " Grid."

OTHER USES

Removing the truck for inspection of the apparatus thus completely isolates it from the supply (Fig. 11 (a) and (b)). Shutters may also be provided to cover up the bus-bars when the truck is drawn and are opened automatically as it is introduced. Interlocks must also be provided to ensure that the breaker is tripped before the truck is removed.



SWITCHBOARD. Fig. 11 (left). A single unit of a truck type board withdrawn from its cubicle. The shutters at the back of the cubicle are visible on the right.
General Electric Co Ltd of England.

The framework for truck type cubicles is built up of angle and channel iron; castings are sometimes used, but they are often not absolutely flat and square, and are liable to fracture in use.

The stationary portion of the cubicle should be provided with rails for the wheels of the truck, to ensure accurate alinement between the plugs and receptacles, independently of variations in the floor level.

If a perfectly level floor cannot be provided, " T " or flat irons may be let into the floor to form a level path for the truck wheels, or a loose sheet steel plate may be laid on the floor when a truck is to be withdrawn. Five inches diameter is the minimum size of wheel which is satisfactory, and the wheels should have a broad face. If undue force has to be used to insert or withdraw a truck, the resulting shocks may damage instruments mounted on the board, or cause the contacts of relays on adjoining panels to fall and trip the switch.

Moulded Stone or Brickwork Cubicles. Stone or brickwork cubicles are usually employed for situations where heavy short circuits may be expected, and for this reason, it is usual to provide separate compartments for each item of equipment, together with phase separation, to localize the effects of a breakdown of any one part. It is usual to fit sheet steel doors of not less than $\frac{1}{8}$-in. thickness, providing vent pipes leading out of the cubicles for breakers of high rupturing capacity. Bus-bar trough covers may be made of asbestos sheets, framed in small sections to facilitate handling.

Cubicles with duplicate bus-bars are usually of the double-fronted type, and may be erected on two sides of a partition wall. In large power stations or main substations, where large oil circuit breakers are required and the cubicles

SWITCHBOARD. Fig. 12. Isolating switch and instrument transformer cells of a remote mechanically operated brickwork cubicle switchboard for a 66-kV, 3-phase, 50-cycle system
Johnson & Phillips, Ltd.

oil circuit breakers and potential transformers from the other apparatus, leaving the fronts of the cells open or covering them with expanded metal; in this country it is customary to carry the separation much farther and steel plate doors for the cells may be said to be standard practice.

If single-phase circuit breakers are used in groups of three for each circuit the separation of the phases may be carried right through the installation, giving great security against faults between phases.

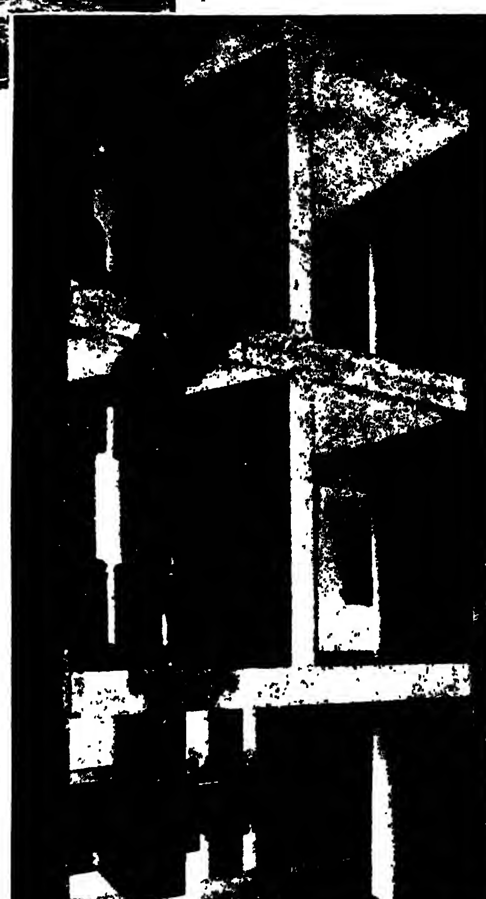


Fig. 13. Bus-bars and connexions of 11,000-volt G.E.C. cubicle switchboard showing mica-wrapped conductors and bakelite boxes on the joints.

contain a full equipment of instrument and protective transformers, etc., two storey cubicles may be necessary.

Cubicle Board Practice. Of late, the cubicle board has yielded in favour to metal-clad compound or oil-filled gear. In spite of this the cubicle board has a number of advantages compared with the metal-clad type. The first of these is great simplicity and accessibility of all parts for cleaning. It is true that the insulators require rather more cleaning than is the case with iron-clad gear, but if the cubicles are soundly constructed and the doors fit well, this should not be onerous. It must not be forgotten that when a thing is cleaned it is also inspected and regular inspection is most conducive to trouble-free service. When all the conductors and most of the insulators are immersed in oil or compound inspection is practically impossible.

Stonework cubicle boards vary in the amount of separation that is provided between the different pieces of apparatus and between the phases.

In Germany it is common practice to separate each circuit from the neighbouring circuits by a wall, and in some cases the

Frequently the bus-bars are separated by partitions, but in order to reduce expense three-phase breakers are used so that in the breaker cells all three phases are together (Fig. 12). Usually each set of isolating links, each set of fuses, each potential or current transformer and each circuit breaker has a separate cell, the connexions passing from one cell to the next by means of insulated bushings.

It is common practice to insulate the conductors in cubicle switchboards, not, of course, for the full voltage to earth, but sufficiently to guard against the danger of voltage surges causing flash-overs. Several layers of insulating tape over all the conductors and joints is generally sufficient. On important installations wrapped-on mica insulation on the straight conductors with bakelite boxes on the joints has been used (Fig. 13). This makes an excellent job but is naturally somewhat expensive. Whatever may be done, the conductors in and adjacent to the oil switch cells should always be insulated, as it is there that flash-overs occur most often.

Potential Transformers in Cubicle Boards. Mounting potential transformers in cubicle boards is often a troublesome business, as many as three cells having to be allotted to each transformer. This difficulty can be overcome by mounting the transformers and their fuses in small trucks similar to those of the truck type switchboards above, which are run into cells on the lower part of the board. Removing a transformer thus isolates it automatically.

Isolated Phase System. Particularly in America the principle of isolated phases has been carried to the extreme, each phase with its corresponding switches and apparatus being housed in an entirely separate building, no metallic connexion between the three buildings being permitted which could possibly lead to a flash-over causing a short between phases

Iron-clad Switchgear. Unless isolation on both sides of the oil switch is required, draw-out iron-clad gear possesses no advantage over switchgear with isolating switches between the oil switch and bus-bars and a complete system of interlocks. Compound-filled gear is not necessary for voltages of 3,300 or below, except, perhaps, for mining use below ground, but when compound-filled gear is used, the instrument transformers should be oil-immersed so that they can readily be changed for others of different ratio should occasion arise.

Fine Wiring. For back of panel use single-core fire-proof cable is employed, flexible cable being used where conductors have to cross door hinges. Connexions between cubicles and control boards may be of multi-core armoured cable or single-core cables run in conduit; the latter method has the advantage that conductors can be added with a minimum of expense, provided that conduit of ample size is installed in the first instance.

Standard Finish. The usual finish for switchboards is black with nickel relief on the raised parts of instruments, oil switch escutcheons, etc.

Sheet steel plates may be enamelled and polished, but a dull black finish, obtained by spray painting and stoving, looks well and is very durable. Cubicles are sometimes painted battleship-grey when required to harmonize with the colour used for painting machinery and structural ironwork.

Tropical Finish. Certain precautions have to be taken in the design of various items of equipment for switchgear for use in a tropical climate.

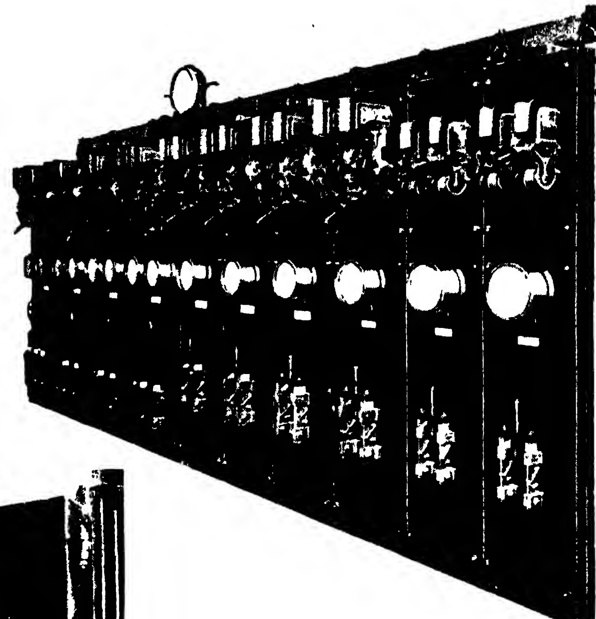
Metal scales are essential for instruments and relays, some of the metal parts may have to be plated, and special care is needed in the insulation and impregnation of windings. There must be no holes through which insects may enter.

Instrument transformers must be designed with a large margin of safety. Potential transformers for use on circuits above 3,300 volts are more reliable when oil-immersed, and current transformers may with advantage be of the oil-immersed or compound-filled type for voltages above 6,600.

Special care must be paid to painting, and small screws, etc., should be of brass wherever possible. If the plating is done thoroughly, instruments may be finished in nickel relief or all-black finish and should be periodically cleaned with a rag lightly smeared in vaseline.

Cable trenches underneath the switchboard should be covered, taking the cables in and out through bushes which tightly fit the cable.

Direct Current Switchboards. Direct current switchboards for the control of generators and main feeders usually are of the flat-back type, with the circuit breakers, knife switches, etc., mounted on the front of the panels, and the bus-bars and connexions behind. A typical switchboard of this type is illustrated in Fig. 14. Continental design favours dead-front switchboards, the switches and circuit breakers being mounted on the back of the panels and operated from the front by means of suitable levers.



SWITCHBOARD. Fig 14 Flat-back switchboard for use on a medium-tension 2-wire D.C. system.
Johnson & Phillips Ltd

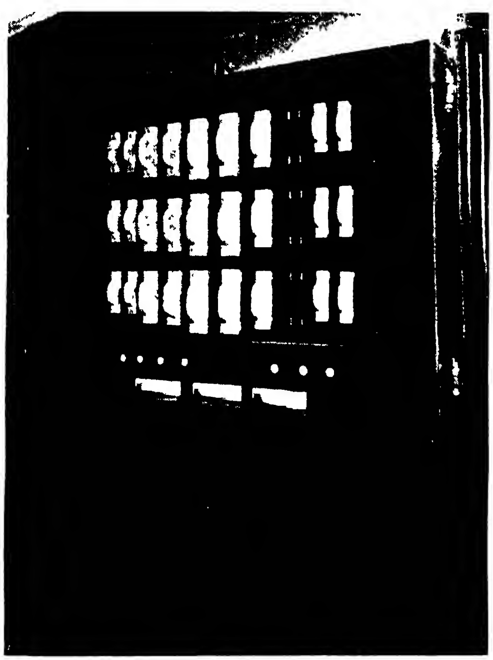


Fig. 15. Iron-clad distribution board for medium-tension 3-phase systems.
Johnson & Phillips, Ltd.

This construction considerably increases the cost, and as main switchboards are operated by attendants possessing a certain degree of skill, while working pressure of such installations on D.C. systems rarely exceeds 500 volts, it is difficult to justify the extra cost. Flat-back switchboards are satisfactory under average conditions, but in very dirty positions, such as in cement works, they must be placed in a room apart from the works; it is a very expensive matter to construct totally enclosed iron-clad switchgear for the control of D.C. generators and feeders of any considerable size.

General Switchboard Lay-outs

Medium-Tension Distribution Switchboards, A.C. and D.C. Distribution switchboards for industrial use may be of the flat-back type, if the Home Office recommendations can be met, and the switchboard is not required for use in a very dirty or damp situation. Totally enclosed iron-clad air-break switchgear is higher in first cost, but the saving of space which the use of this type of gear permits usually counterbalances the extra cost if the capacity of the circuits to be controlled does not exceed about 200 amps., and the number of instruments is reduced to a minimum. Fig. 15 illustrates a typical iron-clad distribution board mounted against a wall. For use in very exposed positions, such as foundries, a drip-proof sheet steel type of distribution cubicle is available. In this cubicle the phases are "stepped" so as to give a straight run for the cables

and to facilitate connecting up. Sheet steel distribution cubicles are often cheaper than cast iron gear when non-standard requirements have to be met.

Where direct current is used in collieries or in chemical works it may be necessary to employ totally enclosed oil-break switchgear to withstand the severe conditions of dirt, corrosive fumes, etc., which are encountered.

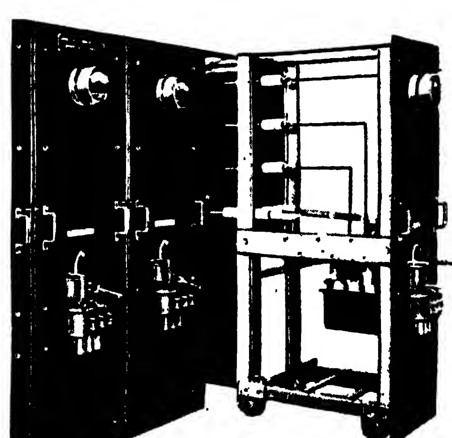
Medium-Tension A.C. Switchboards. For medium-tension A.C. systems the available types of switchboards are more numerous and a choice correspondingly more difficult. Flat-back switchboards may be used, and as oil circuit-breakers are almost exclusively employed on main A.C. switchboards, all live apparatus can be mounted behind the panels. The arrangement of the apparatus behind the panels renders it difficult to carry out repairs or adjustments with the circuits alive, and either the switchboard must be shut down or isolating switches be provided on each circuit, preferably with barriers between the panels. As no live gear need be mounted on the panels they may be of sheet steel, which gives a cheap and serviceable construction. The disadvantage of the flat-back board is the floor space required, the necessary passage-way in front and behind totalling, with the depth of the switchboard proper, about 8 ft.

Next in order of cheapness to the flat-back board is the totally enclosed sheet steel cubicle type. This type of switchboard can be made reasonably dust-proof, and is therefore more suitable for some situations than an open-type board. Isolating switches are nearly always provided in cubicle type gear, and a simple and cheap interlock can be fitted between the oil switch and the isolating switch chamber door to ensure that the oil switch is opened before the door, thus reminding the attendant to open the isolating switches before working on the oil switch, etc. Provided the switchboard is not required for use in a very dirty or damp situation, the cubicle type of construction will be found to meet most substation and industrial requirements. When arranged for front access, the depth required, including the necessary working space in front, is about 6 ft.

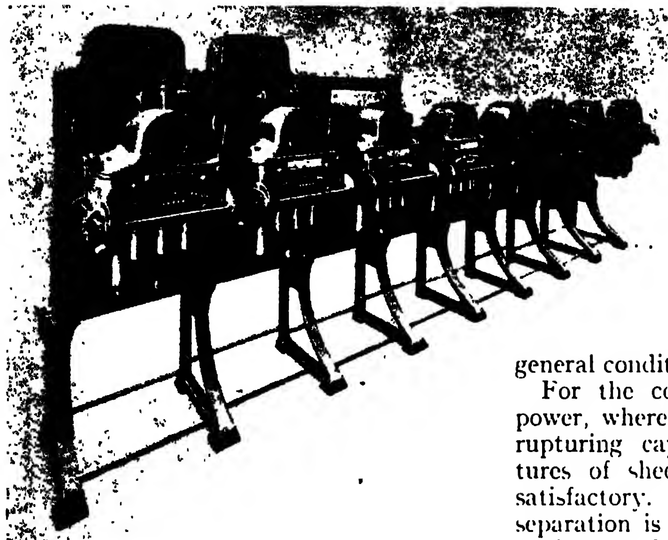
The draw-out truck type switchboard possesses a number of advantages over the stationary cubicle type. All apparatus which requires periodical inspection or cleaning is mounted on a withdrawable truck which makes contact with the fixed bus-bars and cable terminals by means of plugs and receptacles. Interlocks are provided, and patent automatic shutters, which completely screen live metal when the truck is withdrawn. Unskilled labour can be employed for cleaning, and there is no possibility of accidental contact.

No passage-way is required behind the switchboards, the overall depth required, including space for withdrawal of the truck, being about 6 ft. This depth is about the same as that required for a front access stationary cubicle, but it is much easier to work on a truck when it is withdrawn than on the gear in a stationary cubicle. Fig. 16 shows a typical truck type switchboard with one of the trucks withdrawn.

For simple feeder and transformer control boards where indicating instruments only are required, the iron-clad pedestal type construction makes a compact and inexpensive arrangement. The majority of installations do not require isolators on both sides of the oil switch, and a non-drawout type can be provided with bus-bar isolators and interlocks, and is therefore suitable for operation by unskilled attendants.



SWITCHBOARD. Fig. 16. Draw-out truck type switchboard with truck withdrawn. 6,600-volt 3-phase system.
Johnson & Phillips, Ltd



SWITCHBOARD. Fig. 17. View of 3,300-volt, 3-phase iron-clad switchboard as used in non-fiery mines and other industrial sub-stations
Johnson & Phillips Ltd

This type of gear is dust-proof and can be made weather-proof, and is thus suitable for use under the most severe conditions. Having been designed as an inexpensive type of apparatus for industrial and mining (non-fiery) use, this type of switchgear is not arranged to accommodate a large number of indicating instruments, watthour-meters or special forms of protective gear such as the Merz-Price. Fig. 17 illustrates a typical iron-clad switchboard provided with isolating switches.

H.T. and E.H.T. A.C. Switchboards. For sub-stations and small power stations where an oil circuit breaker having a rupturing capacity not exceeding about 100,000 kVA is required, either the stationary sheet steel cubicle or the draw-out truck type switchboard may be employed. The latter type shows a saving in space compared with the back access stationary cubicle, but it is usually possible to arrange stationary cubicles for front access only, although both back and front access is recommended where space permits. If full interlocks are provided, the cost of the two types is approximately equal, but the stationary cubicle can be provided more readily with separate compartments for potential transformers, oil circuit breakers, etc., thus localizing the effect of a breakdown of any component part. The truck type cubicle is more accessible for cleaning and repairs and does not require so much headroom as a stationary cubicle, but being a standard production does not always lend itself to special arrangements to suit unusual requirements. Either type is satisfactory, however, for general conditions.

For the control of large amounts of power, where oil circuit breakers of high rupturing capacity are required, structures of sheet steel are not altogether satisfactory. For such work, phase separation is desirable, and each item of equipment should be housed in a separate compartment so as to minimize the risk of the spread of fire resulting from a breakdown of any item of equipment. Moulded stone or brickwork cubicles make a satisfactory arrangement, the oil circuit breaker being arranged for remote operation, either electrical or mechanical, the operating lever or controller and the instruments, relays, etc., being mounted on a control board of the flat-back or desk type.

Compound-filled iron-clad switchgear may also be used for important installations, but it is considerably more expensive than a stonework cubicle arrangement. The saving in space resulting from the compact design of compound-filled gear counterbalances the extra initial expense for very large or very high voltage installations, but for the average switchboard, for, say, an 11,000-volt system with 25,000 kVA of generating plant, there is little saving in floor space, and the height of the building is usually fixed by considerations other than the height of the switchgear.

For 3,300-volt service, where large rupturing capacity is not required, the iron-clad type switchboard described under medium-tension switchgear may be employed, subject to the limitations previously mentioned. This class of gear is, of course, essential for colliery use.

Fig. 10 on the plate shows a five-panel drop-down switchboard for controlling an 11-kV supply from the British "Grid."

These panels are of the sheet-steel fabricated construction, the circuit breakers being of the heavy-duty, circular tank type giving a particularly robust construction.

Control Boards are of the flat-back or desk type, but the former is preferable as instrument wiring is much more accessible.

SWITCHBOARD. Fig. 18. 11,000-volt G.E.C. high-tension stonework cubicle switchboard installed at Hams Hall Power Station, Birmingham, showing solenoid-operated oil circuit breakers

Control boards for large stations preferably should be installed in a room apart from the engine-room, so that the attention of the attendants is not distracted in the event of trouble to the running plant; in this case, a proper system of signalling to the machine attendants, and a duplicate synchroscope in the engine-room, would be provided. If the control board must be mounted on the gallery in the engine-room, and it is thought necessary to arrange for the attendant to be able to see over the board into the engine-room, a desk type board must be provided, but in practice it is found quite convenient to provide a flat-back board with the front facing the machines, as the switchboard attendant need not face the machine driver when giving hand signals to raise or lower speed, etc. In small stations the machine driver can often read indicating instruments from the engine-room with a fair degree of accuracy when the control board faces the engine-room, and a knowledge of the approximate load being taken by the machines is a helpful check on the reading of the turbine instruments. (*See further under* Switchgear.)

The Care of Switchboards: Cleaning. Marble or enamelled slate must not be cleaned with an oily rag, but, when necessary, with a damp, soapy cloth. Enamelled slate may be polished with the aid of a little boot polish and a soft rag. Oiled slate may be cleaned by first dusting with a dry cloth, finishing off with a clean

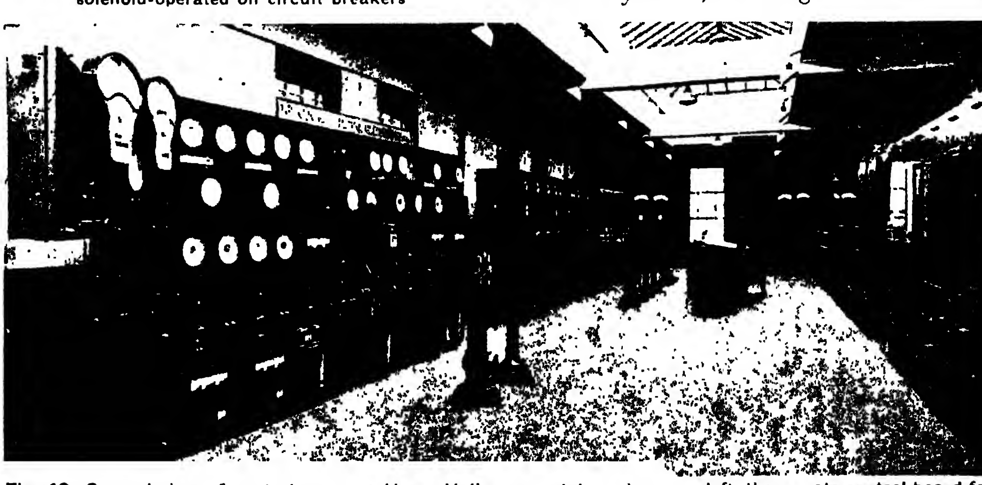


Fig. 19. General view of control-room at Hams Hall power station showing, left, the remote control board for the 11,000-volt gear in Fig. 18 and, right, the remote control boards for the 460-volt D.C. switchgear.
General Electric Co., Ltd., of England

rag moistened with linseed oil. Metal polish should not be used on the bright finish of instruments, or the plating, however substantial, will disappear in a year or two; a clean rag with a trace of vaseline will give quite a bright finish and will prevent rust.

Routine Inspection. As far as possible all trip-coils, closing solenoids and similar apparatus should be tested weekly. If a circuit breaker is not tripped occasionally it may fail to operate under fault conditions. Opening and closing a switch a number of times every week also assists in keeping the contacts bedded, and it is recommended that this practice be adopted for all heavy current switches which have to carry continuously a current in the neighbourhood of full load.

Relays can be operated by hand to ensure that the moving parts are free, and attention paid to see that the cord in relays of the weight-winding type is in its groove or pulley. Oxidation of the mercury in mercury cup contacts may be prevented by covering the surface with oil.

If a primary battery is used for operating shunt trip-coils, an ammeter, push button and resistance should be provided for testing purposes, the resistance being equal to the resistance of a trip-coil, and a red mark made on the ammeter scale to indicate the minimum current which will operate the trip-coil.

It is very necessary periodically to clean up the main and arcing contacts of air-break and oil-break circuit breakers, any blobs of molten metal being filed down. Unless badly burnt arcing contacts are replaced they will eventually fail to protect the main contacts from damage.

As soon as possible after a fault, it is advisable to inspect all circuit breakers which may have been affected, cleaning up contacts and adding oil to replace any which may have been expelled.

The oil in circuit breakers and current and potential transformers may be filtered and used again, or replaced with new oil, annually, or oftener in the case of breakers which are frequently called upon to operate under load. The oil in heavy current circuit breakers tends to sludge in time, thus preventing proper circulation and causing overheating, and the use of non-sludging oil is recommended.

SWITCHBOARD PANEL. *See* Panel.

SWITCH-FUSE. There are many situations where the protection afforded by a fuse (*q.v.*) is ample in case of overload or short circuit, but where it also is desirable to be able to break the circuit for the purposes of repairs, etc. Such cases arise where small supplies are tapped off H.T. or L.T. systems. One solution is to put a switch in series with the fuse. An economy can, however, frequently be made by combining both into a switch-fuse.

The requirements of such an apparatus are:

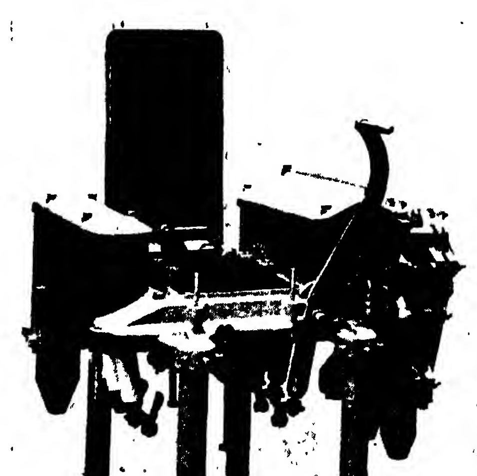
1. As a switch it must be capable of interrupting the normal full load current of the circuits which it supplies.

2. As a fuse it must be capable of interrupting the maximum possible short-circuit current at the point where it is installed.

3. If the fuse blows at the instant the switch is being opened the operator must be completely protected.

4. The fuse must only be accessible for changing when in the open position; there must be no risk of touching live parts while carrying out this operation.

Generally the fuses are enclosed in a box, which can only be opened when the switch-fuse is open. The fuse itself, or a holder in which the fuse is fixed, is arranged to pivot and bridge over between the two fixed contacts. The act of opening the circuit may be used to operate



SWITCH-FUSE. Fig. 1. 11,000-volt oil-immersed G.E.C. switch-fuse, with tank lowered and fuses in position for re-wiring.

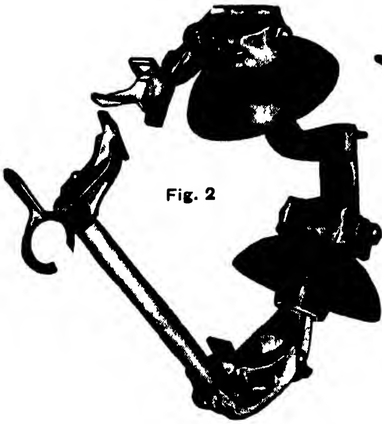


Fig. 2

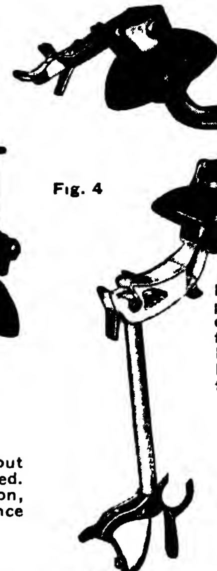


Fig. 4

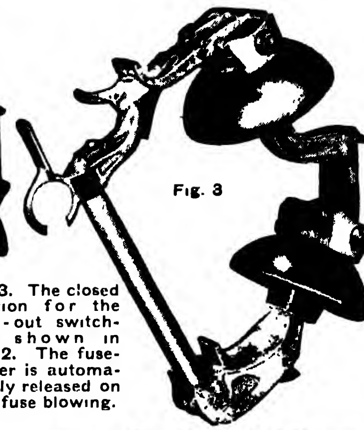


Fig. 3

Fig. 3. The closed position for the drop-out switch-fuse shown in Fig. 2. The fuse-holder is automatically released on the fuse blowing.

SWITCH-FUSE. Fig. 2. J. & P. drop-out switch-fuse, just prior to being closed. The switch is arranged for pole operation, and the action can be followed by reference to Figs. 3 and 4.

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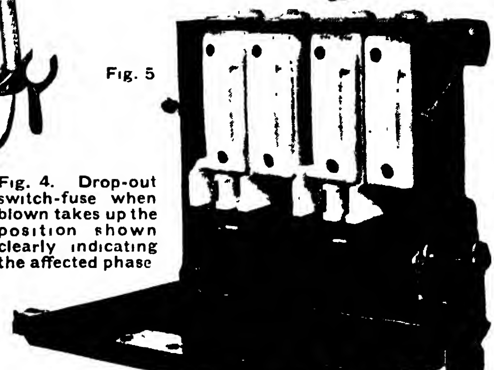


Fig. 5

Fig. 4. Drop-out switch-fuse when blown takes up the position shown clearly indicating the affected phase

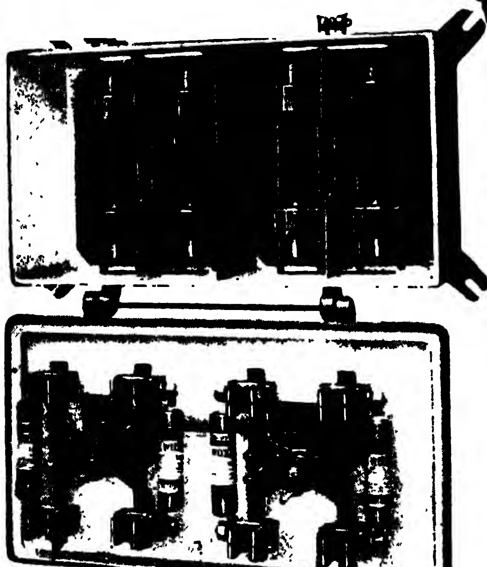


Fig. 5. Low-tension iron-clad switch-fuse as employed in factory and other installations.

General Electric Co., Ltd., of England.

Fig. 6

Fig. 6. "Safetee" combined switch-fuse, D.P. change-over, or 4-pole for A.C. or D.C 500-volt supply.

L. Weeks (Luton), Ltd

Fig. 7. Combination switch-fuse with non-deteriorating cartridge fuses of 25,000-kVA rupturing capacity.

English Electric Co., Ltd

Fig. 7

a pair of shutters which cover up the fixed contacts and prevent accidental contact with them.

For high tension, switch-fuses are often immersed in oil. Fig. 1 represents an iron-clad model which is made up to 33,000 volts. Fig. 5 is another for low-tension circuits.

Figs. 2, 3 and 4 show an automatic "drop-out" switch-fuse used for overhead lines. The fuse wire holds a catch which in turn holds the switch closed. On the fuse blowing the catch is released and the fuse-holder drops out of the upper contact and is left hanging so indicating the phase affected. The device can be operated and the fuse replaced by an insulated pole.

In Fig. 6 is a change-over switch-fuse for 500-volt A.C. or D.C. supply. A feature of this type of switch-fuse is that it is only possible to have one switch in the "on" position at a time. Both switches can, however, be "off." For further examples *see* Fuse; Oil-Break Fuse; Switch, *etc.*

SWITCHGEAR IN MODERN POWER PLANTS.

By C. C. Garrard, Ph.D., M.I.E.E., A.Am.I.E.E., and C. J. O. Garrard, M.Sc.

In the broadest sense of the word the term switchgear covers all apparatus for making and breaking electric circuits and regulating the current flowing in them. Many particular aspects of the subject are dealt with under Switch, Protective Devices, Relay, Starter, etc., and reference should be made to these headings. This article deals with the apparatus which is interposed between the generators and the distributing feeders, or between the feeders and the point of utilization to regulate the distribution of current to the different users. It should be studied in conjunction with the preceding article, Switchboard. See also Arc ; Blow-Out ; Bus-Bar ; Circuit Breaker; Contactor; Switch-Fuse.

The elements from which a switchgear installation is built up are the following :

(1) Fixed bus-bars and connexions;

(2) Movable isolating switches, connecting links, etc., which are used to connect up the different sections of fixed conductor and bus-bar ;

(1) and (2) together serve to *direct* the current in the desired channel.

(3) Devices such as switches, air-break circuit breakers, oil circuit breakers, fuses and reactances, which are used to *control* the current and prevent dangerous conditions ; and finally

(4) Measuring instruments, with their corresponding shunts, current and potential transformers, etc., which are used to *measure* the current.

It is necessary to distinguish between the two sorts of switches mentioned above. Isolating or sectionalizing switches, or disconnecting links (*q.v.*) as they are variously called, are switches used to link up different parts of the bus-bars, to connect circuits to the bus-bars and so on. They should not be used, however, for making or breaking circuits in which a current is flowing or would flow were the isolating switch in question closed. Circuit breakers (*q.v.*) are capable by their construction of making and breaking the heaviest current likely to be met with on the particular system.

Isolating switches generally have circuit breakers in series with them, which should be open before the position of the isolating switches is changed.

We will begin by considering the principles involved in the lay-out of these elements to form the complete installation and then go on to discuss the apparatus of the switchboards.

I. Lay-out of Switchgear

The most important factor in the design of a switchgear installation is the lay-out of the main circuit diagram. This must be simple and clear and exactly adapted to the end in view. The amount of money which one is prepared to spend on switchgear will vary very much with the type of load, and whether this will allow of short interruptions of supply or whether continuity is of paramount importance, as, for instance, in central stations. The installation should, however, be confined to that which is absolutely necessary, as all superfluous apparatus, besides increasing the expense, adds to the risk of breakdown.

The plan generally adopted in installations of whatever size is to have a series of conductors called bus-bars (*q.v.*) which are maintained continuously under tension and to which are connected the individual circuits from the generators or to the feeders. It follows from this that the main diagram, or schematic diagram as it is sometimes called, should be built up of a number of unit sections each corresponding to a single outgoing or incoming circuit. These units should, for the sake of simplicity and interchangeability, be as nearly alike as possible.

It is essential to grasp the principles involved in the design of individual circuit units before attempting to construct complete circuit diagrams. The same applies to complete wiring diagrams of installations (the term " wiring diagram " is used for diagrams containing all the detail of the fine wiring for control and measuring circuits as well as the main conductors). It is of no use attempting to study complete wiring diagrams before the principles underlying the component parts have been mastered. In the same way the correct method of constructing circuit diagrams and wiring diagrams is to decide how many and what kind of circuits are necessary and how each should

be arranged, what lay-out of bus-bars will be most advantageous, and finally piece the whole scheme together from its component parts.

Arrangement of Bus-bars. This must satisfy the following requirements:

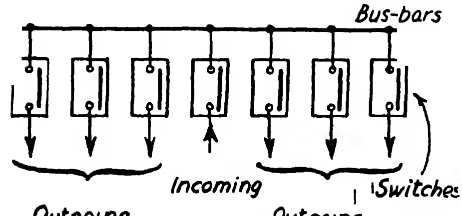
(A) The arrangement must be as simple and clear as possible consistent with providing the means of meeting all conditions likely to be met with in exploitation, including abnormal conditions due to breakdowns of apparatus, outages, and so on.

(B) Each incoming or outgoing circuit must be capable of being opened or closed without disturbance to the other circuits.

(C) It should be possible to isolate each part of the installation for repair or cleaning without interrupting the supply.

The simplest arrangement of bus-bars consists of a single set of conductors (the number being 1, 2, 3, 4, or more, depending on the system of distribution in use), which are maintained constantly under tension by the source of supply, and from which the requisite number of outgoing circuits is tapped off. Fig. 1 shows this diagrammatically. It should be noted that the diagrams used here are "single-line" diagrams, *i.e.* each line represents one, two, three, or more conductors, *e.g.* for a three-phase system each line represents three conductors.

The single bus-bar system has the disadvantage that, if a breakdown occurs on the bars, or if it is required to make them dead for cleaning or repair, the whole of the gear must be shut down. To avoid this, double bus-bars are used (Fig. 2). Each incoming and each outgoing circuit can then be connected to either of the two sets of bars, so that one set can be made dead without affecting the other or the supply. Where economy is important each branch circuit is provided with one oil switch only, which is connected to one



SWITCHGEAR. Fig. 1. Single bus-bar system.

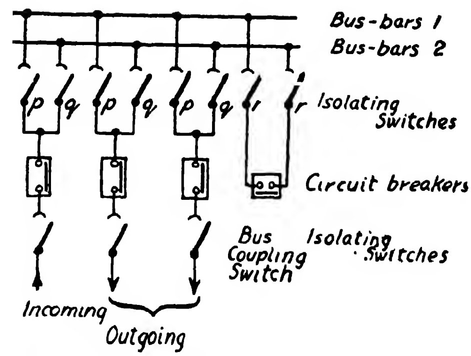


Fig. 2 Double bus-bar system with one circuit breaker for each circuit.

or other of the two sets of bus-bars by means of two sets of isolating switches (Fig. 2).

Occasionally two circuit breakers are used for each circuit (Fig. 3). This is, however, a somewhat expensive measure.

Bus-Coupling Circuit Breaker. With double bus-bar systems it is customary to

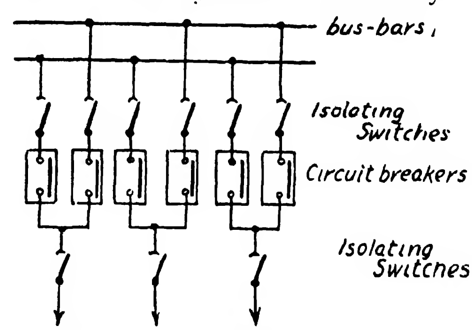
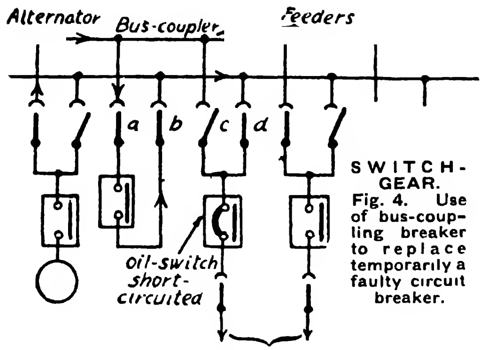


Fig. 3. Double bus-bar system with two circuit breakers per circuit.

have a bus-coupling breaker, *i.e.* one that can be used to connect the two systems of bus-bars together (Fig. 2). This serves a variety of purposes, the chief of which is to divide or parallel the two sets of bars when for any reason it is desired to run them separately. It is clear that to separate one set of bars from the other by means of an isolating switch while both were under tension would be dangerous, while to parallel them under the same conditions would be impossible without shutting down one part. The bus-coupling circuit breaker enables both these operations to be carried out safely. It should be closed as an additional safeguard during the time that feeders or generators are being changed over from one set of bars to the other. Thus



SWITCHGEAR. Fig. 4. Use of bus-coupling breaker to replace temporarily a faulty circuit breaker.

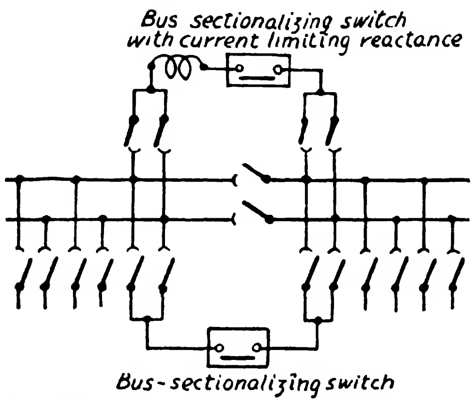


Fig. 5. Method of connecting bus-sectionalizing switch and reactance to double bus-bar system.

(referring to Fig. 2) bus-bars 1 might be in operation so that isolating switches *p* are closed. To change over to bus-bars 2, first the isolating switches *r* are closed, and then the bus-coupling breaker; after this, isolating switches *q* are closed and *p* are opened. Finally the bus-coupling breaker is opened, followed by its isolating switches *r*.

The bus-coupling breaker may be used to replace temporarily a breaker which has been damaged (Fig. 4), and so on.

Bus-bar Sectionalizing Switch. It is frequently convenient to be able to divide the bus-bars into several sections. In order to do this bus sectionalizing switches or breakers may be provided (Fig. 5). These are frequently used in conjunction with current-limiting reactances as shown in Fig. 5. The bus sections can either be connected directly together (when, for instance, the total capacity of the generators connected is small and the short-circuit power limited), or by means of the reactances when the total connected capacity is large. Another and better arrangement is to provide a "tie-bar" (Fig. 6). Here sectionalizing switches are provided, but the reactances are not connected directly between the bus-bar sections, but between these and the "tie-bar." For further discussion of this point *see* Protective Devices.

Auxiliary Bus-bar. This is a device frequently used on the Continent. A reserve or auxiliary breaker is provided, which can be connected to either of the sets of main bus-bars, and which feeds an auxiliary bus. This can be connected to any one of the outgoing or incoming circuits by means of isolating switches, and enables the breakers belonging to these circuits to be examined without interrupting the supply (Fig. 7).

Ring Bus-bar System. The flexibility of an installation may be increased by

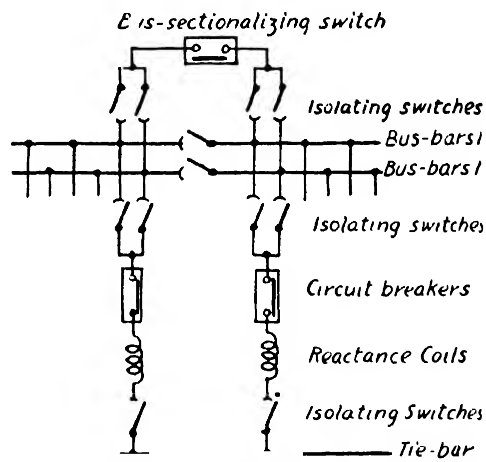


Fig. 6 Use of bus-sectionalizing switch and tie-bar with current limiting reactances.

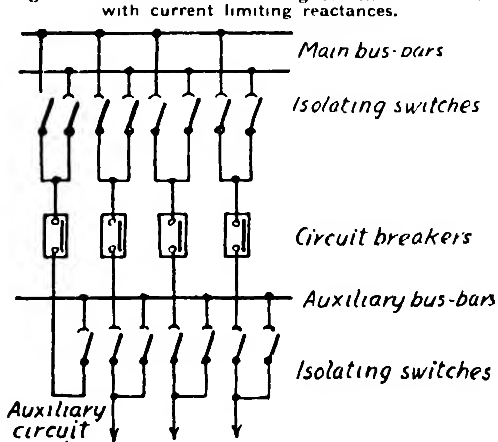


Fig. 7. Lay-out showing application of auxiliary bus-bars to a double bus-bar system.

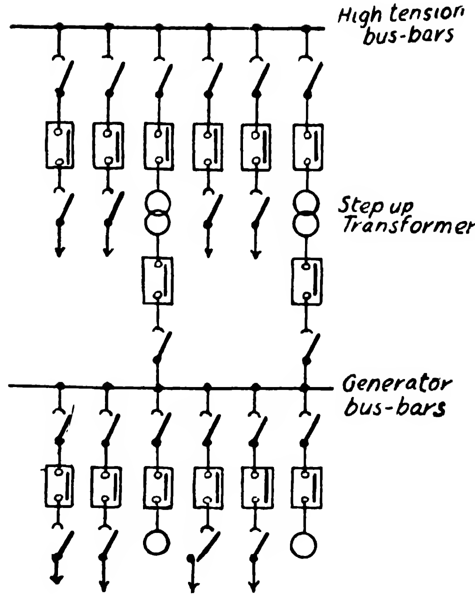
connecting the two ends of the bus-bars together to form a ring. It thus becomes possible to connect one part of the bus-bars to another by two alternative routes. The maximum of flexibility is probably given by a duplicate ring bus with a series of sectionalizing switches, each section of duplicate bus being provided with a bus-coupling switch (Fig. 9). The combination of this with an auxiliary bus bar as shown in Fig. 7 would allow of dealing with any conceivable contingency that might arise.

Arrangement of Branch Circuits. Once it has been decided how the bus-bars are to be arranged consideration can be given to the branch circuits.

In the case of generator circuits it is necessary to be able to isolate the breaker from the bus-bars. If the breaker is out of service the machine must in any case be shut down so that is no object in having isolating switches on the generator side of the breaker (Fig. 4).

A cable or transmission line may or may not be under tension while the breaker is being handled so that on feeder circuits it becomes necessary to have isolating switches on both sides of the breaker (Fig. 4).

Earthing Switches. These are frequently used for earthing the outgoing ends of overhead lines so that work can be carried out on the lines without fear of their becoming live or electrostatically charged. The earthing switch is often combined with an isolating switch (*see* Fig. 39).



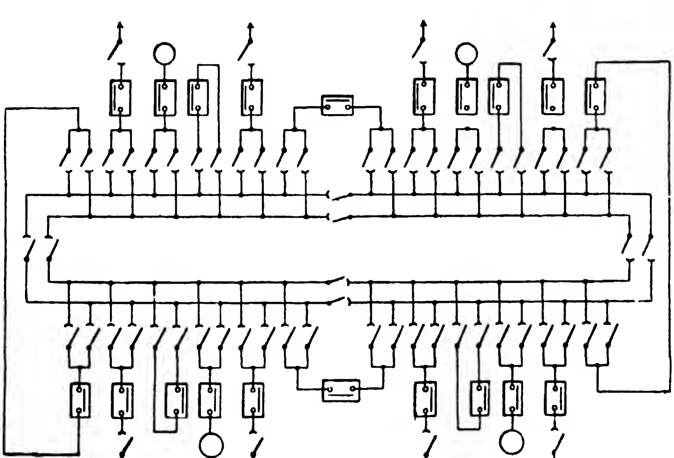
SWITCHGEAR. Fig 8 Use of bus-bars at generator voltage and on the H T side of the step-up transformers, with feeders connected to both sets of bars. (Single bus-bars are shown, but in general double bus-bars would be employed for such a scheme.)

Choice of Bus-bar Voltage. The voltage is naturally determined to a considerable extent by the use to which the current is to be put.

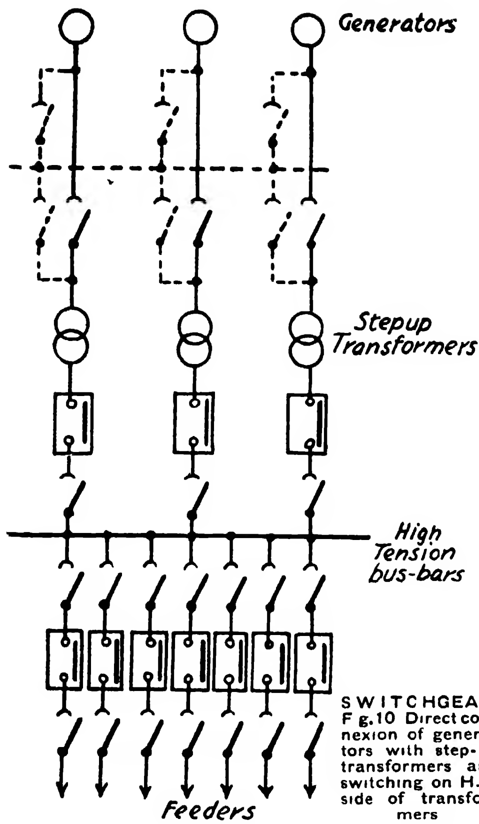
For distribution, pressures up to 250 volts are most common, while three-wire systems (*q.v.*) generally have up to 500 volts between the outer conductors. For tramways 500–600 volts is most common, while for D.C. traction 600, 800, 1,200, 1,500 and 3,000 volts are used.

It is only when one comes to the generation and distribution of large blocks of power that considerations other than the purpose for which the current will be used become important, and have an influence on the arrangement of the switchgear.

Alternators are commonly built to generate at 6,600 to 11,000 volts. Machines are



SWITCHGEAR. Fig. 9. Double ring bus system with bus-sectionalizing and coupling switches.



SWITCHGEAR Fig.10 Direct connexion of generators with step-up transformers and switching on H.T. side of transformers

at present in operation or being built for 22,000 or 33,000 volts. It remains to be seen whether this will become general. If it does it will only be for very large machines, while for medium size machines 11,000 volts will probably remain the commonest value. As long as the distances over which the bulk of the current must be transmitted are not so great as to render the use of 6,600 to 11,000 volts uneconomical it is most convenient to build the switchgear for this voltage, and connect the local feeders direct to the generator bus-bars (Fig. 8).

A limit is set to such voltages for very large stations by the difficulty of dealing not only with the short-circuit current but also with the normal current. It is found that for 50-cycle circuits it is very expensive and inconvenient to construct switchgear and connexions for currents above about 3,000 A. This corresponds to 34,000 kVA at 6,600 volts, three-phase. Machines of this size are common to-day.

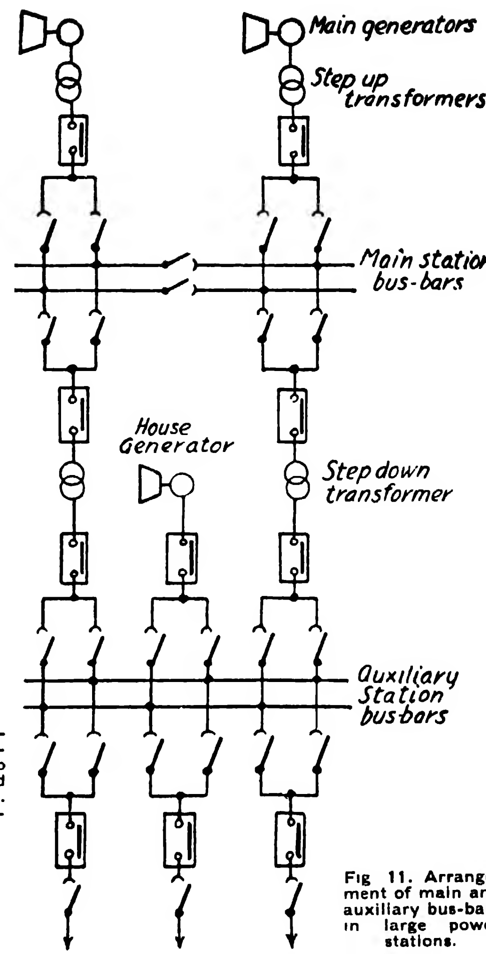


Fig 11. Arrangement of main and auxiliary bus-bars in large power stations.

If several such machines are in the same power station it becomes advisable to switch at a higher voltage so as to reduce the magnitude of the currents. In this case each alternator is coupled directly to a bank of transformers the switchgear being on the H.T. side of these transformers (Fig. 10). This is the arrangement commonly employed for large modern power stations (*e.g.* Battersea, where the generator voltage is 11,000 volts and the switchgear 66,000; St. Denis, Paris, generator 10,000 volts, switchgear 60,000 volts).

Occasionally an auxiliary bus-bar is used (shown dotted in Fig. 10) to enable any generator to be connected to any transformer. This does not meet with favour in the case of very large units, however, as the added complication of the heavy isolating switches is undesirable.

Power Station Auxiliaries. The reliability of a power station is dependent to a great extent on the right method being adopted for supplying the motors of the auxiliary services, such as feed pumps, fans, condensing water pumps, etc. When these are of moderate size D.C. can be used with a battery to guard against interruptions. A battery is always used for the tripping and signal circuits. In large stations it is frequently more economical to use high-tension three-phase motors for the fans, etc. The safest method in this case is to use double bus-bar boards for the auxiliaries, each set of bars being fed from a separate and independent source of supply. One of these may be the main station bus-bars and the other special house generators. One such arrangement is shown diagrammatically in Fig. 11. Where auxiliary circuits are fed directly from the main bus-bars care must be taken that the breaking capacity of the circuit breakers used is sufficiently great. In general this must be the same as for the main circuit breakers, as the possible short - circuit power on the auxiliary circuits will be the same as on the main circuits. If step-down transformers are used as in Fig. 11 the short-circuit power is limited by the reactance of the transformers.

II. Selection of Switchgear

Once the lay-out of the bus-bars and circuits has been decided upon, the next step is to determine what kind and size of circuit breaker and switchgear is to be installed. It is not possible to deal exhaustively here with the multitudinous designs and types of switchgear that are upon the market and with the reasons that lead to the choice of any one of them in different circumstances. All that can be done is to give a general description of the commoner types with indications of the service for which they may be used.

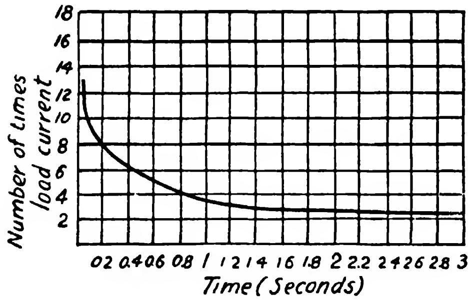
There are, however, certain general considerations which influence the choice of switchgear and which may be mentioned. These are stated below.

(A) Normal Voltage and Current. The voltage of the supply is the factor which has the greatest influence on the type of switchgear used in a given case. The higher the voltage the greater must be the distance between conductors of different polarities and the stronger must be their insulation. While low-tension apparatus can be mounted on slate or marble slabs with small spacings, the use of high tension necessitates either large spacings between the conductors, as in H.T. outdoor switchgear, or surrounding them completely with a substance of high dielectric strength, as with H.T. compound-filled gear.

When the tension is elevated, the currents are normally of moderate value and it is only on L.T. circuits that very heavy normal currents are encountered. Here the chief object is to reduce ohmic drop and heating of conductors and contacts. This leads to the use of open type gear with very heavy conductors, strongly supported to resist the electrodynamic forces in case of short circuit.

(B) Short-Circuit Power of the System. As the purpose of switchgear is not only to direct and control the flow of current but to interrupt it when it attains a dangerous value, the circuit breakers used must be capable of interrupting without damage the severest short-circuit currents (*see* Short Circuit) that can occur at the point in the system where the gear is installed, *i.e.* they must have a sufficiently large breaking capacity. In fact, the choice of high-tension switchgear is determined almost entirely by the necessity of having a sufficient breaking capacity. This is defined (B.S.I. Spec. No. 116) as "the maximum R.M.S. current at rated working pressure, or the maximum kVA which the switch will break under prescribed conditions at stated intervals a specified number of times. The value of the maximum kVA is the product of the rated working pressure in kilovolts and the actual current at the time of separation of the contacts, multiplied by 1, 1·73, or 2 for single-phase, three-phase or two-phase systems, respectively."

In the early days of the use of oil circuit breakers, system short-circuit powers were small and little trouble was experienced with explosions and failures to clear faults. After the war, however, when large power networks began to develop, particularly in America and on the Continent, much difficulty was experienced on this score, and it was soon



SWITCHGEAR. Fig. 12. Short-circuit current characteristic of system fed by synchronous machines based on 10 per cent. total reactance and initial full load conditions

realized that the apparatus then in use was totally insufficient for the short-circuit capacities resulting from the linking up of numbers of large power stations. The establishment of short-circuit testing plant and much research on arc phenomena have resulted in enormous strides being made in oil circuit breaker construction and also in the partial supersession of oil circuit breakers by compressed air and expansion switches. At the time of writing the matter is in a state of flux and it is difficult to forecast what system of construction will crystallize out of the present experiments.

Determination of Necessary Breaking Capacity. When a fully excited alternator running at full speed is short-circuited the short-circuit current that flows in the first instant is very much greater than the steady short-circuit current that would flow were the machine first short-circuited and then run up to speed and excited. The reason for this is that the initial rush of current is determined solely by the generated E.M.F. and the leakage reactance of the alternator windings. It is only after the short circuit current starts flowing that it can exercise its demagnetizing effect and reduce the E.M.F. of the machine. The result is that in the first instant of the short-circuit a current flows that may be as large as 20 times the normal full load current. This decreases at first very rapidly, then afterwards more slowly until after 2 to 3 seconds the sustained short-circuit value is reached, which may be from 2 to 3 times the full load current (Fig. 12).

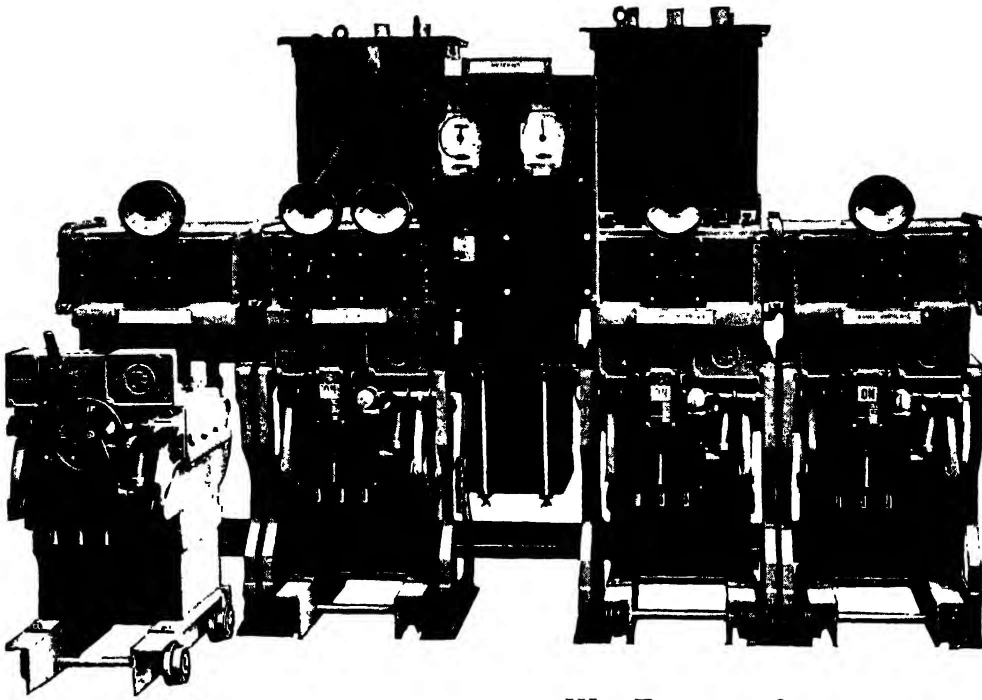
In practice, the protective gear and the oil circuit breaker itself have a certain time lag, so that a breaker is not called upon to interrupt the initial current peak. The B.S.I. recommends that where there is no reactance in the circuit except that of the alternators, which is assumed to be 10 per cent., the breaking capacity of the breakers should be about 6 times the normal full load capacity of the installation. Where current-limiting reactance coils, transformers or lengths of transmission line are interposed between the breakers and the generators, this value may be reduced accordingly. Modern turbo-alternators are built with very high reactances, which also tends to reduce the severity of short-circuits.

The choice of the switchgear to be installed at any point on a system must therefore be based upon calculations (*see* Short Circuit) of the severest possible short-circuit that could occur at that point under any possible condition of loading of the network. The breaking capacity of the switchgear must then be such as to allow a reasonable margin of safety above the calculated value.

There are short-circuit testing stations now in existence in this and other countries where breakers may be tested under short-circuit conditions even more severe than those occurring in practice, so that in a few years' time we may hope to see breaking capacities guaranteed almost as accurately as kVA. load capacities of machines can be guaranteed at present.

(C) Security Against Short-Circuit Currents. If it is essential that the circuit breakers be capable of interrupting the maximum possible short-circuit current that is to be expected on the system, it is none the less important that the other parts of the gear be able to withstand the mechanical and thermal effects of short-circuit currents without damage.

On heavy short circuits the electro-dynamic force between two adjacent conductors of a set of bus-bars may be very considerable, amounting in some cases to several hundred pounds per foot run. It thus becomes necessary to support the bus-bars very strongly, preferably with insulators in the plane of the three conductors and on both sides of each bar so as to work always in compression. For the same reason tubular or U-shaped bars are sometimes used instead of strip as they are more resistant



SWITCHGEAR. Fig. 13. Switchboard controlling two incoming feeders from the "Grid," and two outgoing feeders, equipped with duplicate bus-bars. The bus-bar coupler panel is the centre.
Switchgear & Cowans, Ltd

to bending; tubular bars have also the advantage of having no sharp edges which can set up brush discharges or corona (*q.v.*); they also have lower A.C. resistance.

A further precaution which must be taken is to guard against the possibility of spontaneous opening of isolating links and breakers due to the tendency of the electric circuit to increase its periphery. The forces involved are considerable and may be sufficient to open an air isolating link or separate the contacts of an imperfectly designed circuit breaker with disastrous results. To guard against this, isolating links are frequently provided with locking devices and circuit breakers are sometimes so designed that the electromechanical forces tend to force the contacts together instead of opening them.

The minimum size of conductor that may be employed in a switchboard is frequently limited not by the normal current but by the short-circuit current, as it is essential that the heating caused by the short-circuit current should not be so great as to damage the conductors.

III. Types of Switchgear

In the following paragraphs the chief characteristics of the commoner types of switchgear are described.

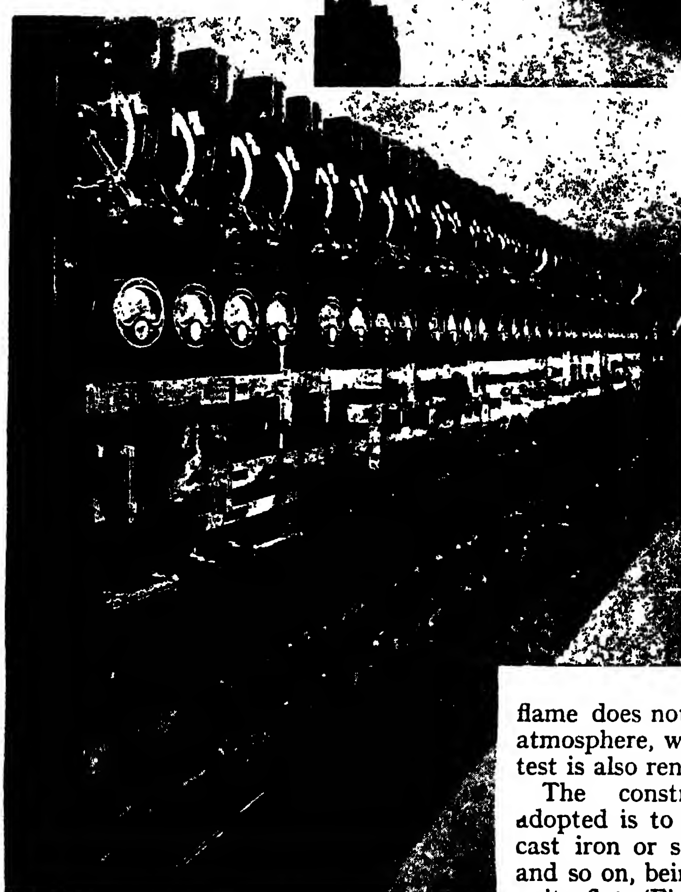
Switchgear is generally arranged in the form of switchboards and the arrangement and construction of such boards is discussed under the heading Switchboard.

Low-Tension Iron-clad Switchgear. Iron-clad switchgear is gear of the type in which all live parts are enclosed in an earthed metallic casing. It is extremely useful in tropical climates, in situations where vermin is prevalent and in mines where safety to human life is of paramount importance, and is made for all voltages and breaking capacities from the smaller industrial and mining types up to the largest super-generating station requirements. We deal here with small iron-clad gear, leaving consideration of the larger types until later.

Apart from its use for isolated switches on individual circuits, the most important application of iron-clad gear is for building up unit-type boards. For lighting, and small power installations, machine shops and the like, this type of board finds ever-increasing favour. It is built up from standard cast-iron or steel sections, each

containing a switch, a set of fuses or a section of the bus-bars. Used in conjunction with armoured cables or steel conduit it makes an excellent job, being little affected by dust and moisture, very flexible and readily extended. A form of iron-clad gear is the distribution pillar used for urban distribution and installed in the open air on the side of the pavement. *See also* Distribution Board *and* Feeder Pillar *with* Plate *facing page* 508.

Mining Gear. For collieries, oil refineries



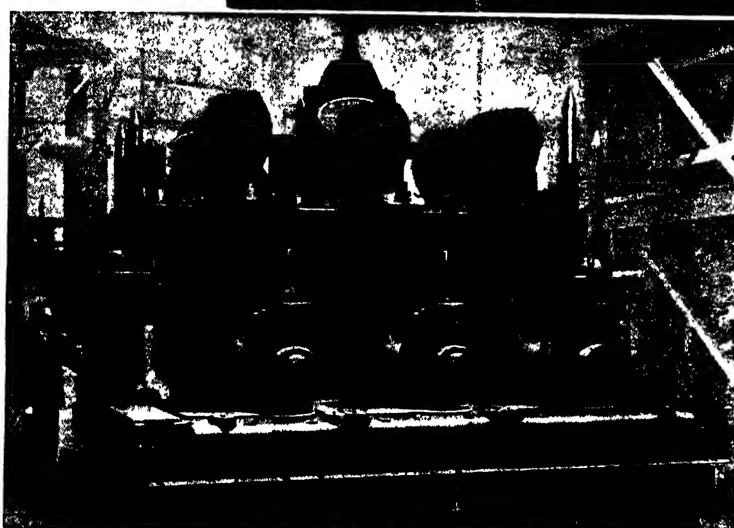
SWITCHGEAR. Fig. 14. Five-panel internal isolation switchboard installed in a consumer's sub-station for 11,000 volts, 3-phase, 300 amps., 75,000 kVA rupturing capacity.
Switchgear & Cowans, Ltd.

Fig 15. Switchboard with front of panel bus-bars installed in a London sub-station.
J. G. Statter & Co., Ltd.

and other situations where explosive mixtures of air and gases or vapours are liable to occur, iron-clad gear is essential, as it is the only form which lends itself to explosion-proof construction. In order that gear may be said to be explosion-proof, it must be so enclosed that, on the ignition of an explosive mixture inside the case, the explosion or flame does not communicate itself to the atmosphere, which for the purpose of the test is also rendered explosive.

The construction most frequently adopted is to make the cases of massive cast iron or steel, the joints of the lids, and so on, being very wide and machined quite flat (Fig. 16). When the cover is

closed a gap of several thousandths of an inch is left between it and the case. The pressure produced by an explosion inside can then escape by the joints, but the gases on escaping are so cooled by their passage



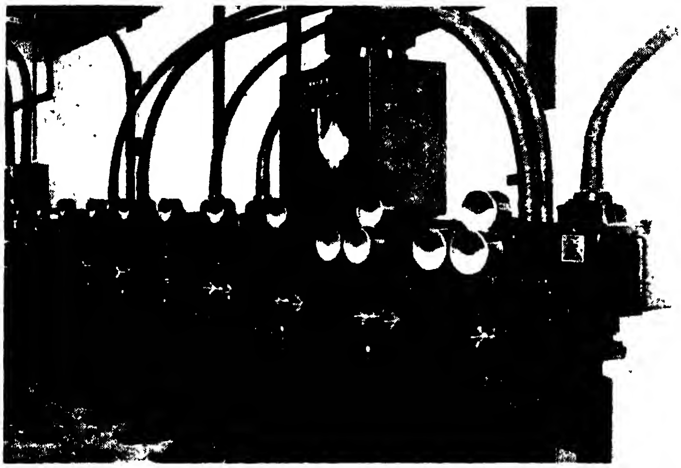
SWITCHGEAR. Fig. 16. (above). Iron-clad distribution board for colliery use.
Johnson & Phillips, Ltd.

Fig. 17. (left). Close-up view of 66,000-volt oil circuit breaker supplied to the Battersea power station of the London Power Company.
Metropolitan-Vickers Electrical Co., Ltd

Fig. 18. 66,000-volt oil-filled, metal-clad switchgear for Battersea power station of the type shown in Fig. 17.
Metropolitan-Vickers Electrical Co., Ltd.

over the metal surfaces that they are not capable of igniting an explosive mixture outside. Such switches are frequently installed on the unit system, as shown, for instance, by Fig. 16.

Ironclad construction, which was originated for low-voltage mining and industrial gear, has in recent years been adopted for all voltages in common use. It is now standard practice for voltages up to 35 kV, a number of installations for 66 kV are in operation, and experimental plant for 132 kV has been erected.



SWITCHGEAR. Fig. 19. Industrial metal-clad compound-filled internal isolation switchgear

Switchgear & Cowans, Ltd

Fig. 21 Bus-bar section of 11-kV. compound-filled gear. The tubular bus-bars are shown before the compound is poured in, also the connexions to the sockets on the bottom right-hand side.

High-Tension Metal-Clad Gear. Certain features of this design are common to all makes. The conductors are mounted in boxes of cast iron or sheet steel, and the space between them and the walls of the box filled with compound or oil (Fig. 21). The compounds vary in consistency from hard, resin-like material to a thick, syrupy liquid. The hard compounds have a high dielectric strength, but are liable to crack on cooling or if the case receives a heavy blow. On the other hand, fluid compounds or oil are liable to leak out of the case unless the joints are very carefully sealed. On the whole the best sort is probably of medium consistency, with a tough or rubbery nature which prevents the formation of cracks. The pouring temperature should be about 65° C. (*see* Compound Filling).

For extra high-tension gear (*e.g.* 66 kV) condenser bushing type insulation (*q.v.*) is generally used for the conductors, which, therefore, approximate to high-tension cables. In such cases oil filling is adopted, as it is absolutely essential that there be no voids or cracks which would lower the dielectric strength. The passage of conductors from one compound-filled space to another may be effected either by passing them through bushings or

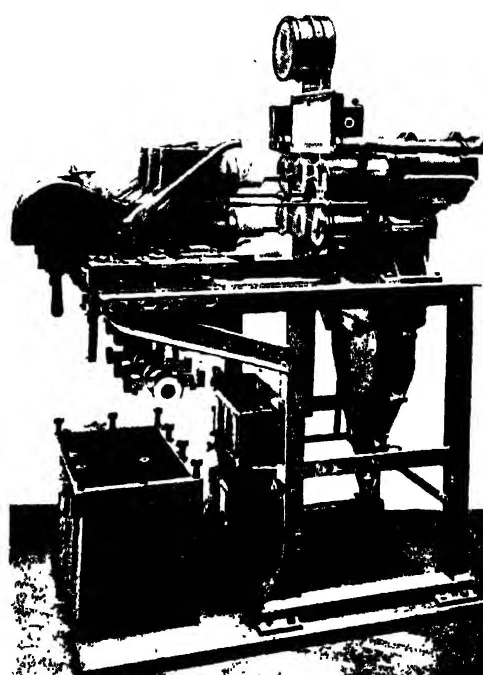


Fig. 20. All-enclosed metal-clad switchgear with circuit breaker racked out and tank lowered.

A. Reyrolle & Co., Ltd.

through plates of insulating material.

The bus-bar chambers are generally carried by a number of supports and form a fixed structure to which the oil circuit breakers are attached. The connexion between the bus-bars and the breakers is by a series of plugs and sockets, the plugs being mounted on the breaker terminals and the sockets at the extremity of female recessed insulators, into which the breaker terminals are inserted and which are either mounted directly in the bus-bar chambers or in the ends of spouts which communicate with these.

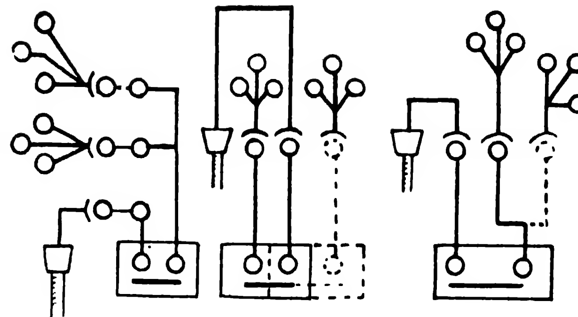
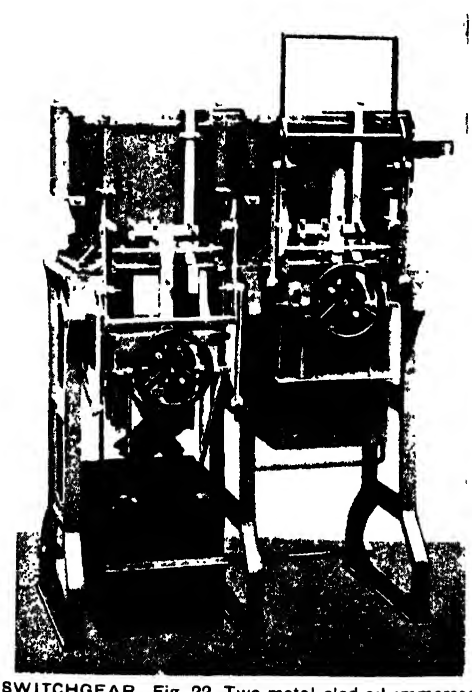


Fig. 23. Systems of bus-bar selection used in metal-clad gear. (A) Horizontal draw-out, with screwed-in plugs. (B) Vertical draw-out, translation of complete breaker. (C) Vertical draw-out, rotation of one circuit breaker terminal.

In installations of any size duplicate bus-bars are generally used, so that the problem of bus-bar selection must be solved. The circuit breakers are almost invariably (except in very large E.H.T. gear) isolated by being withdrawn from their plugged-in position. Where the conditions of service allow it the bus-bar selection may be carried out in the same way, either by having two fittings on each terminal on the bus-bar side of the breaker, into either of which a plug may be screwed, thus making contact with one or other of the bus-bar systems (Fig. 23, A), or by moving the breaker bodily from one set of fixed sockets to the other (Fig. 23, B), or, finally, by mounting one terminal of the breaker eccentrically and arranging it so that it can be turned (Fig. 23, C), and so make contact with either bus-bar.



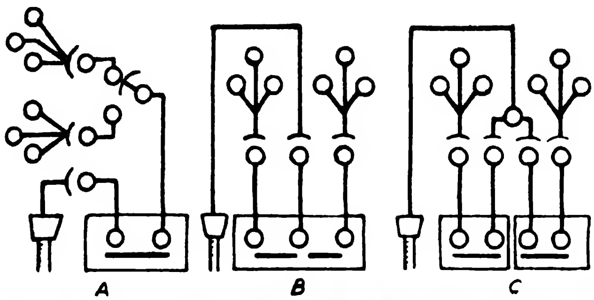
SWITCHGEAR. Fig. 22. Two metal-clad oil-immersed switches, one isolated and one with tank removed.
A. Reyrolle & Co., Ltd.

Any of these somewhat lengthy methods of bus-bar selection necessitates the interruption of the supply to the circuit while the breaker is being changed over from one set of bars to the other. If this is inadmissible recourse must be had to some form of selector switch. This may be a simple, oil-immersed isolating switch with a wide blade making contact with one set of contacts before leaving the other (Fig. 24, A).

If rapid change-over is wanted, and particularly if it is desired to effect the change-over from the control-room, two methods are available. The breakers may be provided with three instead of two sets of fixed contacts, and two sets of moving blades, which can be closed either separately or together (Fig. 24, B). Alternatively, duplicate circuit breakers may be used (Fig. 24, C).

When either of these arrangements are used a bus-coupling breaker is no longer necessary, as the circuit breakers themselves serve the same purpose.

Vertical and Horizontal Draw-out. The circuit breakers are disconnected from the bus-bars by removing them from their plugged-in position. This may be done



SWITCHGEAR. Fig. 24. Methods of bus-bar selection allowing change-over under load. (A) Separate change-over switch with broad blade. (B) Double oil circuit breaker. (C) Duplicate circuit breakers.

by moving them either vertically, *e.g.* Fig. 23B and Fig. 25, or horizontally, Fig. 23A and Fig. 26. For the vertical draw-out type it may be said that it takes up slightly less room than the horizontal draw-out type, and it lends itself to the bus-selecting schemes shown in Fig. 23B and C and Fig. 24C, which are probably the most convenient each of their kind; on the other hand, the lifting gear for the breakers is somewhat complicated and the work involved in raising and lowering the heavy tanks onerous. These difficulties can be overcome to some extent by using special lifting trucks with hydraulic operation.

The horizontal draw-out type lends itself to the plug-selecting scheme (Fig. 23A) and to the selector-switch method (Fig. 24A). If vertical movement is used to isolate the breakers, this may be either upwards or downwards. The latter is generally used on commercial equipments and voltages up to 33 kV, while for higher voltages the breakers may be lifted off with a crane. In this case the pots containing the fixed contacts have

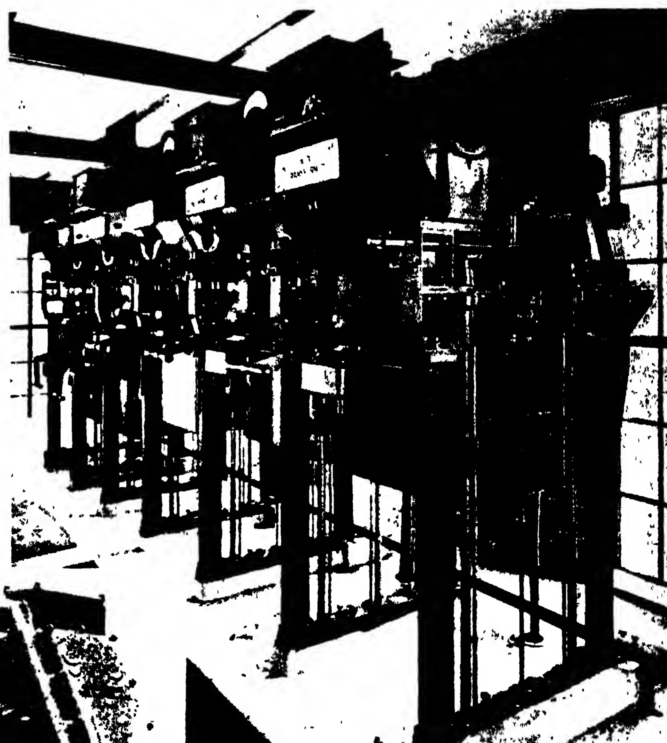


Fig. 25. Single bus-bar 11 kV vertical draw-out iron-clad compound-filled switchboard. The bus-bar chambers are at the top behind the instrument panels. The circuit breakers are raised and lowered each by three screws driven through bevel gears.

General Electric Co., Ltd., of England.

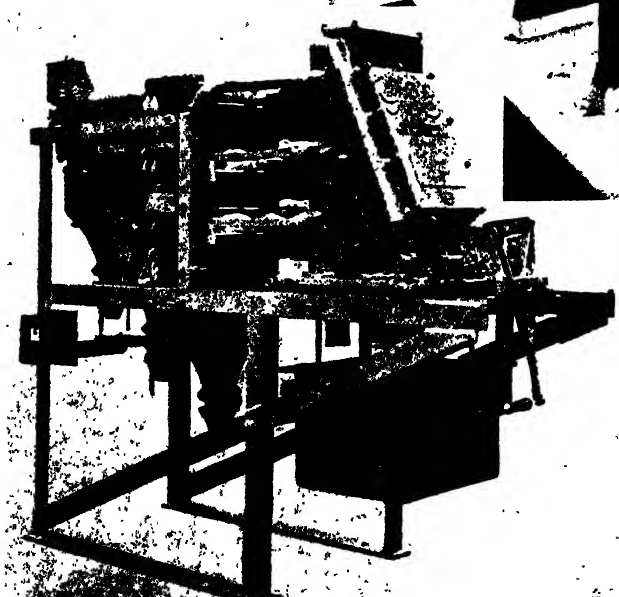
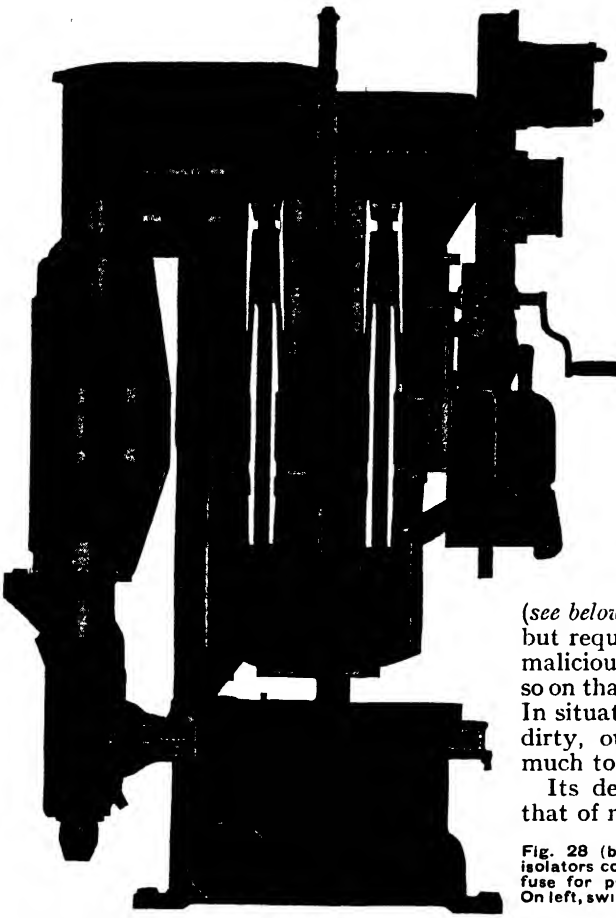


Fig. 26. Unit of 6·6 kV horizontal draw-out switchgear, 100,000 kVA rupturing capacity. This unit is used for tapping-off a ring main.

General Electric Co., Ltd., of England.



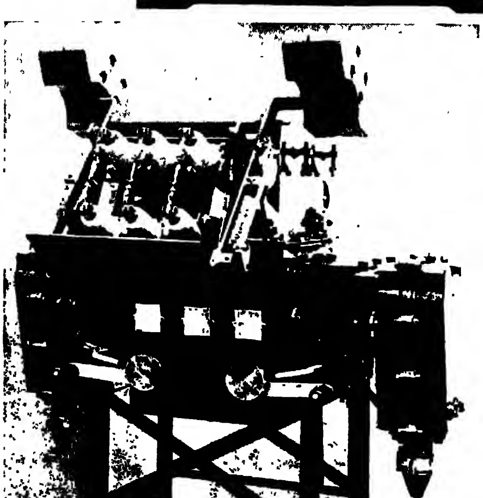
SWITCHGEAR. Fig. 27. Sectional elevation of single bus-bar switch pillar with plug-in potential transformer and additional current transformer chamber.
J. G. Statter & Co., Ltd.

their mouths directed upwards, and can therefore be filled with oil, so that no part of the gear under tension is exposed.

The various makes of iron-clad gear differ principally in the details of contacts, types of insulator, etc., a discussion of which would be out of place.

Outdoor Type Metal-clad Gear. For certain medium-tension sections of the " Grid " outdoor type iron-clad switchgear has been installed. It is also used in a number of power stations in the United States. The 132 kV metal-clad gear mentioned above is also installed outdoors. As compared with open-type outdoor gear (*see below*) it is somewhat more expensive, but requires less space and is less liable to malicious damage by stone throwing and so on than are exposed porcelain insulators. In situations where the atmosphere is very dirty, outdoor type iron-clad gear has much to recommend it.

Its design is not much different from that of normal iron-clad gear except that



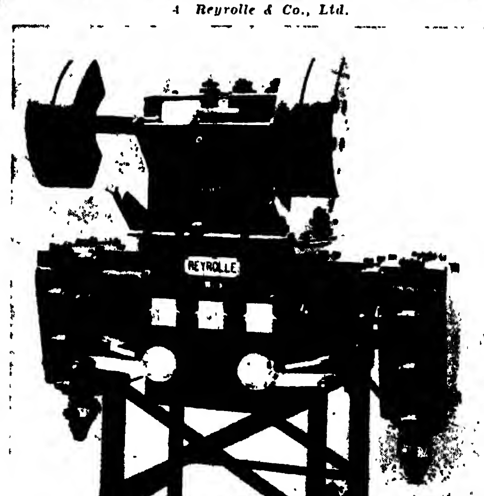
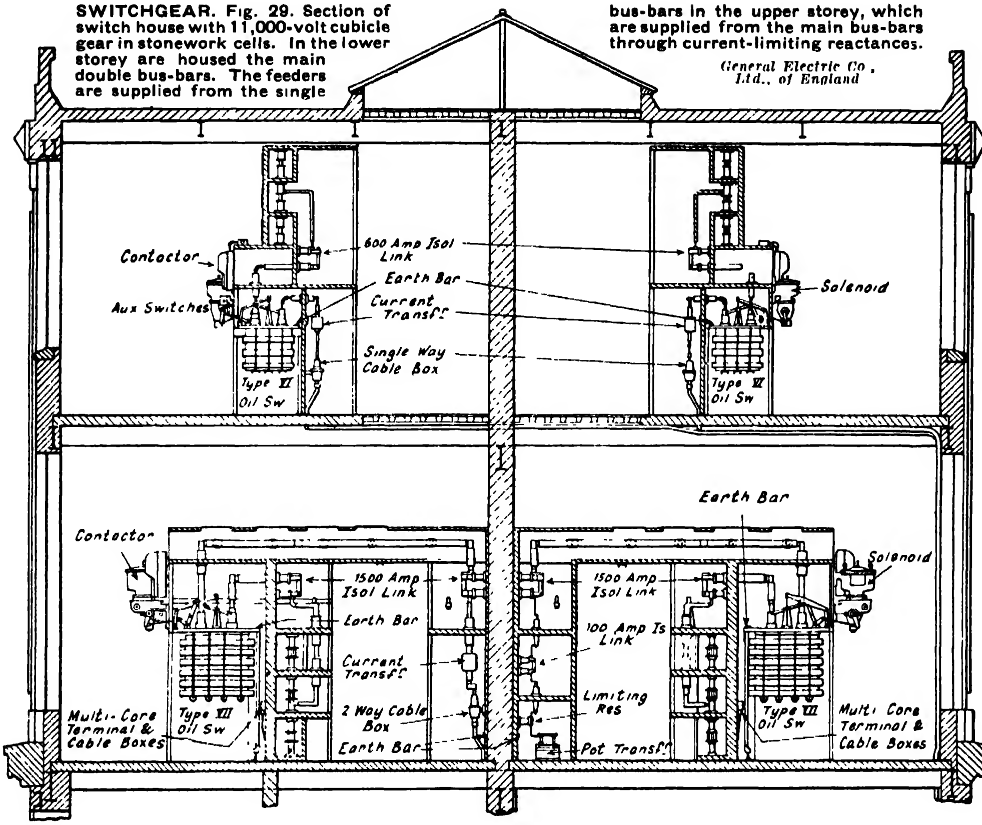


Fig. 28 (below). 12-kV, 3-pole 300 amp. on-load isolators combined with 100 amp. oil-immersed switch fuse for protecting a circuit feed off a ring main. On left, switch-fuse open for inspection; on right, closed.
A. Reyrolle & Co., Ltd.



SWITCHGEAR. Fig. 29. Section of switch house with 11,000-volt cubicle gear in stonework cells. In the lower storey are housed the main double bus-bars. The feeders are supplied from the single bus-bars in the upper storey, which are supplied from the main bus-bars through current-limiting reactances.

General Electric Co., Ltd., of England

slightly greater precautions have to be taken against the entry of water into the apparatus and to protect the breaker trip mechanisms, etc., against corrosion.

For tapping ring mains iron-clad switch fuses are often installed outdoors; they give good results on account of their simplicity (Fig. 28A and B).

IV. Outdoor Type Switchgear

The spacing between conductors in air, which it is necessary to allow in order to prevent danger of flash-overs, increases rapidly with the voltage, so that for tensions of the order of 100 to 200 kV the density of the apparatus becomes very low and the costs of a building, if such be used, extremely high. For this reason installations for about 66 kV and above, where they are not executed with iron-clad gear, are almost invariably installed outdoors. In Germany the "hall" type of construction, which may be said to consist of outdoor type gear installed indoors, has been used up to 100 kV; but for tensions above, this outdoor type gear may be said to be universal. In this country the 132-kV "Grid" sub-stations are all of the outdoor type, and many of the lower voltage sub-stations are outdoor, being composed sometimes of open type, sometimes of iron-clad gear. Outdoor sub-stations are also used where cheapness is the first consideration—as, for instance, in the case with pole-mounted sub-stations for rural electrification.

Lay-out of Outdoor Switchgear. The almost universal method of arranging open-air stations is to mount all heavy apparatus, such as oil switches, transformers, current and potential transformers, on wheels or rollers running on rails supported by concrete foundations. They can thus be moved easily or transferred to a special truck for transport to the repair shop. This apparatus is surmounted by a framework of steel or reinforced concrete which carries the isolating switches and bus-bars and serves to support the connexions when necessary.

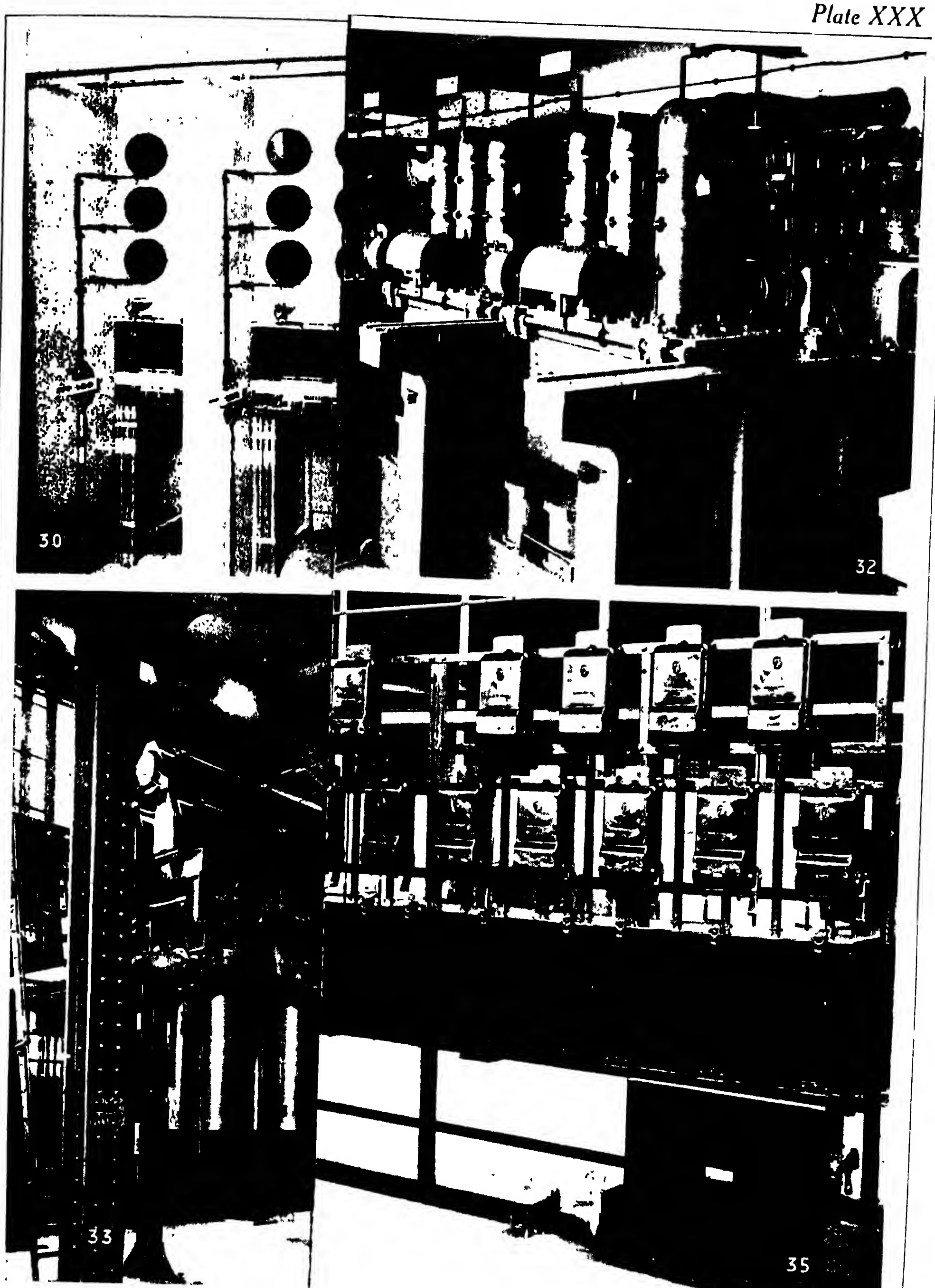


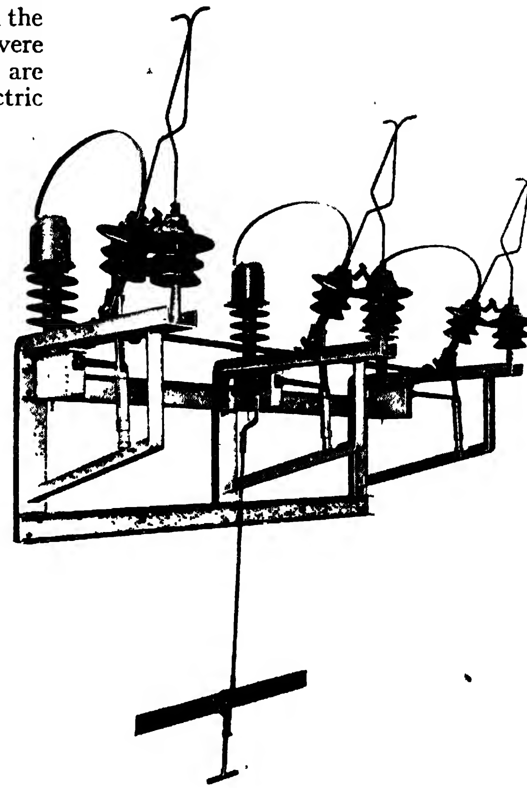
Fig. 30 (top left). Rear view of c n-clad power station switchboard, with vertical drop-down isolation and terminals. Fig. 31 (top centr Fig 34 (bottom centre). Method of mounting 11-kV 3-phase oil on the "Grid." Fig. 32 (top right) icle-type switchboard with separation of phases Fig. 35 (bottom board with 400-amp. 33-kV circ it) 380 220-volt iron-clad unit-type switchboard.

RIAL APPLICATIONS

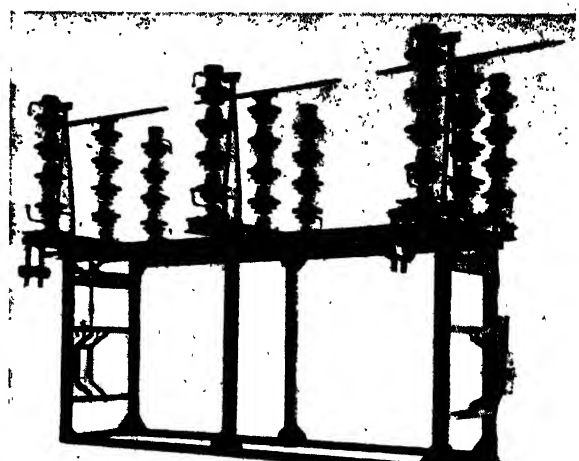
To face page 1224

Apparatus for Outdoor Switchgear. Insulators. Switchgear for installation in the open air is subject to much more severe service than indoor gear. Metal parts are more liable to corrosion and the dielectric strength of insulators is reduced by moisture, rain and dirt. Creepage paths must therefore be longer (use of skirts and ribs on porcelains) and all mechanisms much better protected from the atmosphere than is the case with indoor gear.

Support insulators are either of the post or pin type or of the suspension type (*see* Insulator). For bushings some form of compound or oil-filled porcelain insulator is most commonly used. For higher voltages bakelized paper tubes protected by porcelain bushings are fitted, while for 132 kV and above the condenser bushing (*q.v.*) is almost universal.



SWITCHGEAR. Fig. 36 (top). 33 kV overhead line "Statter" automatic air-break circuit breakers. Fig. 37 (bottom). The only 132 kV metal-clad outdoor switchgear sub-station in the world, on the C.E.B. South Scotland scheme, erected by A. Reyrolle & Co., Ltd.



SWITCHGEAR. Fig. 38 (left). 11 kV single-break hanging-type pole-operated isolating link. Fig. 39 (right). 132 kV double-break isolating switch combined with earthing switch as used on the "Grid."

General Electric Co., Ltd., of England.

Bus-bars. These may be either tubes supported by post insulators or cables (solid, or for extra high tension, tubular) supported by strings of suspension insulators such as are used for overhead lines. For voltages of 100 kV or more the latter is certainly preferable as the quantity of porcelain necessary is much less than when post insulators are used.

Isolating Switches. For small installations and medium voltages pole-operated single-break links are used (Fig. 38). For higher voltages it is safer to use gang operation by means of rods and levers or wires and chains (Fig. 39). Isolating links may be arranged either upright, hanging or vertically; occasionally arcing horns are fitted so that the isolating switches may be used for breaking the magnetizing currents of transformers, and so on (*see* Fig. 20).

Circuit Breakers. For high voltages three-phase breakers generally consist of three single-phase breakers mounted side by side, with common operating gear. Access to the interior is in this case by means of a manhole, as the oil tanks are much too heavy to move about.

For discussion of the lay-out of outdoor switchgear *see* Sub-station.

Remote Control and Interlocking

Remote Control Switchboards. Large switchboards are generally remote controlled either mechanically or electrically. Mechanical remote control by means of rods and levers should be adopted wherever possible on account of its simplicity and reliability. Where this is not possible, either on account of the size of the installation or of the individual switches being too heavy for hand operation, electrical control must be resorted to.

For switch operation solenoids find most favour in this country, whereas in Germany motors are generally preferred. The solenoid has the advantage of being quicker. Pneumatic operation is now being introduced particularly for stations using the new compressed air switches, where a supply of compressed air is in any case available. It has, of course, been used for many years to operate contactors in traction work. A fourth type of remote control is by means of a spring, which, after being wound up by a comparatively small motor, is released, and in expanding closes the breaker. Certain of these apparatus have very small motors which can be fed from potential transformers, making an auxiliary supply for operating the breakers unnecessary. They cannot, however, be operated twice in rapid succession, as it takes a certain time to wind up the spring.

Where remote control is used, signal lamps or position indicators must be provided for all breakers and switches. Two lamps are necessary, one for the open and one for the closed position, to guard against lamp failure.

Control Boards. Where switchboards are remotely controlled it is convenient to assemble all the control switches and

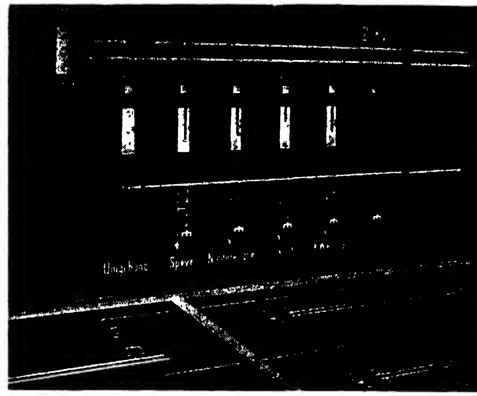
signalling devices and instruments upon a central control board, so that all switching operations and the whole working of the system can be supervised by one operator.

Such control boards are generally either vertical or in the form of a sloping desk. If a desk is used in front of a vertical board, as is sometimes the case, a space should always be left between the two, otherwise access to the apparatus underneath the top of the desk, which is always more difficult than with a vertical board, becomes almost impossible.

Mimic Diagram for Control. For simple installations the usual red and green signal lamps for isolating links and breakers may be sufficient. It is, however, undoubtedly more convenient to use a so-called mimic diagram. The single-line circuit diagram of the installation is reproduced by means of metallic strips on the surface of the control board, the control switches for the breakers being mounted in the diagram in the position occupied by the corresponding breaker The control switches may be so constructed as to act at the same time as position indicators; alternatively separate lamps or electro-mechanical indicators may be used. Another method is to have two diagrams, one embodying the control switches and the other the indicators.

A further development is to construct the mimic diagram of translucent strips which can be illuminated from behind in different colours, the colour of each section of conductor being changed automatically as the condition of the conductor varies. Thus a bus-bar may be red when under tension, white when dead and green when earthed, and so on. When it is desired to perform a switching operation which will alter the electrical condition of any part of the installation, a preliminary movement of the control switch causes all the affected parts to scintillate or blink so that it is possible to tell at a glance what the effect of any operation will be.

Where systems are very complicated and switching operations relatively infrequent it may be possible to dispense with an automatic mimic diagram, and change the position of the indicators by hand as switching operations are carried out.



SWITCHGEAR. Fig. 40. Part of illuminated mimic diagram installed in a large transformer station in Ludwigshaven.
Brown-Boveri, Ltd.

In the United States the so-called miniature control board is very popular. Especially small and compact instruments and control switches, and telephone type indicating lamps are used, so that the superficies of the control board can be so reduced that the operator can reach all parts of it without moving from his chair. The board may be built in the form of a cockpit with the operator in the middle, so that he can reach all parts of it by simply turning round.

Control boards should be suitably enclosed to exclude dust, and the very greatest attention paid to the arrangement of the fine wiring at the back of the board, which may be very complicated (*see* Plate, Fig. 30). A good arrangement for very large boards is to have the control room in three storeys. The control board proper is on the top storey, the relays, meters, etc., which do not need to be constantly under observation, are on the second, while the terminal boxes for the multicore control cables are on the bottom floor.

Great attention should be paid to the numbering and marking of all fine wiring. It is essential that each wire and terminal should have a distinctive mark, and that these marks should be allotted in an orderly and systematic fashion.

Interlocking. In stations where more or less unskilled attendants have to operate switchgear a certain amount of interlocking is necessary in order to prevent mistakes.

In addition to interlocking the doors of the cells of cubicle gear with the

isolating links so that the gear must be isolated before the doors can be opened, it is common to interlock the isolating links with the breaker so that these cannot be opened or closed unless the breaker is open.

Again, if duplicate bus-bars are installed and it is desired to prevent paralleling of the bars by the isolating links, these must be interlocked one against the other so that only one set can be closed at once.

Such interlocks are best when they are mechanical. It is, however, usual with remote control of the breakers to double the mechanical interlocking with an electrical interlock, so that it is, for instance, impossible to attempt to close a breaker that is locked out.

Electrical interlocking is, of course, best where elaborate schemes have to be carried out. In a number of stations erected on the Continent every breaker and switch is interlocked with the rest so that it is impossible to make any mistake in switching. Such elaboration is not much favoured in this country, where simplicity is the most prized virtue in any installation.

A simple and very useful form of interlock can be arranged with a series of keys. Suppose, for instance, an isolator is in series with a breaker. The isolator can only be released by means of a key, which, however, is held by the breaker mechanism unless the breaker is open. In a similar way the breaker cannot be closed unless the key is inserted in its mechanism. A complete interlock is thus obtained. This system, which is extended to very complicated arrangements of interlocking, is much used for "Grid" sub-stations.

SWITCH PLATE. *See* Flush Fittings.

SYMBOLS. The abbreviated representation by means of simple pictorial objects, characters, letters, or other marks of any idea, or operation, or quantity in mathematics, chemistry, and other sciences. The electrician is chiefly concerned with symbols as used in circuit diagrams (*q.v.*). In addition, the following symbols as set forth by the International Electrotechnical Commission are extensively employed:

Length	l	Flux density, electrostatic	D
Work	A	Capacity	C
Energy	W		
Power	P	Dielectric constant	ϵ
Efficiency	η	Self inductance	L
Temperature (Cent.)	t	Mutual inductance	M
Temperature (Abs.)	T	Reactance	X
Period	τ	Impedance	Z
Frequency	f	Reluctance	S
Phase displacement	ϕ	Magnetic flux	Φ
Electro-motive force	E	Flux density, magnetic	B
Current	I	Magnetic field	H
Resistance	R	Intensity of magnetization	J
Resistivity	ρ	Permeability	μ
Conductance	G	Susceptibility	κ
Quantity of electricity	Q	Volt-coulomb	VC
Ampère	A	Watt-hour	Wh
Volt	V	Volt-ampère	VA
Ohm	ω or Ω	Ampère-hour	Ah
Coulomb	C	Milliampère	mA
Joule	J	Kilowatt	kW
Watt	W	Kilovolt-ampère	kVA
Farad	F	Kilowatt-hour	kWh
Henry	H		

m is used for milli, μ for micro or micr, k for kilo, M for mega or meg, and mic for microhenry.

See also Abbreviations; Circuit Diagrams.

SYMMETRICAL VOLTAGE. A system of three-phase voltages which satisfies certain conditions of balancing. In a three-wire system the voltages are symmetrical when each of the values between lines is the same. Since the vectors of these voltages form a closed triangle, their phase differences are alike and equal 120°. With a four-wire system the line-to-neutral voltages are symmetrical if their values are equal and their phase differences 120°. For certain approximate methods of three-phase four-wire metering the instantaneous sum of the three line-to-neutral voltages must always be zero. The voltages need not be symmetrical, provided the vectors of the line-to-neutral voltages form a closed triangle.

SYNCHRONIZER. An apparatus by means of which an indication is given of the occurrence of coincidence in phase and direction between alternating voltage waves derived from two sources. An automatic synchronizer actually closes main switchs when synchronism is attained.

As a rule a synchronizer is used for the purpose of paralleling an additional alternator with one or more already in service. It is also employed for synchronizing groups of alternators running on separate bus-bars and for synchronizing independent supply systems. The modern form of synchronizer is the synchroscope (*q.v.*). The principles involved and earlier forms of synchronizing gear are explained under the heading Synchronizing.

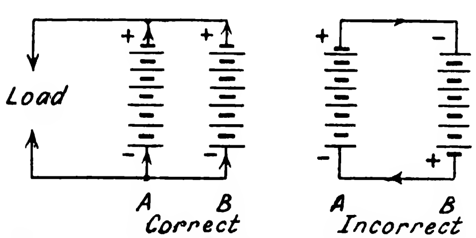
SYNCHRONIZING OR PARALLELING ALTERNATORS

By Arthur Arnold, A.M.I.E.E., A.M.I.Mech.E.

Here the principles involved in switching in two alternators are discussed and the methods and gear used to ensure that phase and polarity are exactly coincident are given. The most modern form of instrument, the synchroscope, is described in the article by the same author that appears in page 1233. See Alternator ; Paralleling.

The process of ascertaining that two sets of alternating voltage waves are coincident in phase and direction, and of connecting them together without causing a disturbance in either. In practice, synchronizing is the process of paralleling alternators.

An elementary consideration of paralleling batteries is instructive. There exists, between the two terminals of battery A (Fig. 1), a steady D.C. voltage, such that one terminal is at a certain potential above that of the other. If now a second battery, B, be connected with one of its terminals to the terminal of A at the lower



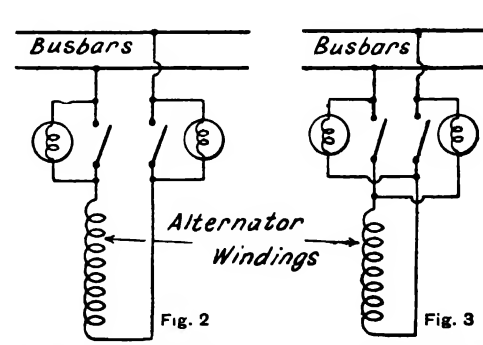
SYNCHRONIZING. Fig. 1. Arrangement for paralleling batteries.

potential, the result of coupling together the other two terminals will depend upon (1) the polarity of the second battery, and (2) the values of the battery voltages. If the second terminal of B is also at a higher potential than the terminal already connected to A, the voltage of B will resist any tendency for A to send a reverse current through B; and if the two voltages be precisely similar, the second terminals can be coupled together (*i.e.* the batteries can be paralleled) without any interchange of current.

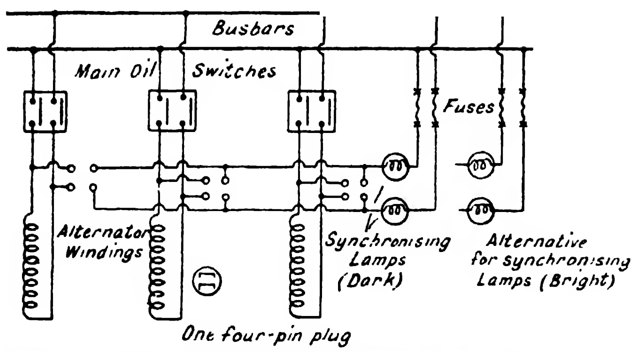
If, however, the second terminal of B be at a *lower* potential than that already connected to A (*i.e.* if its polarity be reversed in respect to A), then, if the circuit be closed, both batteries will be in series, and each will assist the other to send current around the circuit. The condition would thus be equivalent to a dead short circuit and the only limitation to the current flow would be the internal resistance of the two batteries, assuming that the connecting wires were of negligible resistance. If such a mistake were made the wires would either burn out or the batteries be permanently damaged. Similarly, if alternators be coupled together incorrectly the results might be equally disastrous.

Paralleling Alternators. An alternator produces a voltage which is continually changing its polarity, usually 100 times per second. To connect alternators in parallel, we must therefore arrange that the second one also changes its polarity at the same rate, and the connexion must be made at an instant when the incoming voltage is in the same direction, so that the first machine will be unable to send a reverse current. The peak voltage in a positive direction of alternator A must coincide exactly with the peak voltage in a positive direction of alternator B, in point of time as well as in magnitude. It is this necessity for coincidence in time that is the difference between paralleling D.C. generators (or batteries) and synchronizing alternators.

Use of Lamps. At first sight it would appear that nothing less than an oscillograph (*q.v.*) would enable the correct instant for synchronizing to be observed.



Figs. 2 and 3. Lay-out for synchronizing with lamps dark and for using lamps bright for the same purpose —single-phase, low voltage.



SYNCHRONIZING. Fig. 4. Lay-out for plug selection of synchronizing lamps—single-phase, low voltage.

A steady condition being obtained, it is possible to estimate closely the middle of a period of extinction of the lamps, and it is then that the paralleling switch should be smartly closed. At that instant we know that there are quite a number of cycles during which the two voltages are very closely coincident in phase, and therefore they may be paralleled. Coincidence in R.M.S. voltage magnitude can be observed by ordinary voltmeters.

There are, however, much simpler methods. For instance, if the terminals of two alternators be coupled together through a high resistance, the current in the resistance will vary as the difference in their voltages, and when the voltages coincide exactly in both magnitude and time (*i.e.* they are "in phase") the current will be zero. This is the principle involved in synchronizing with lamps.

Assuming that an incoming alternator is running at normal speed and duly excited, its frequency will approximate with that of the bus-bars or of the running alternator. If it is running a little too fast, each cycle will occupy a fraction shorter time than a cycle of the running machine's voltage curve. At some period there will occur an instant in which both voltages pass through zero simultaneously and build up in the same direction. The difference in the two voltages during that cycle (a fiftieth of a second) will be very small indeed.

In the next cycle the difference will be appreciably greater, and so on until, perhaps 50 or 100 cycles later, the zeros will again coincide, but this time the voltages will build up in opposite directions. Their difference will then be a maximum, and it will thereafter gradually decrease again. Thus there is a "beat" effect, which, by slight adjustment of the speed of the incoming machine, can be lengthened or shortened at will. If the high resistance coupling the two voltages takes the form of lamps there will thus be a gradual lighting up and going out, at a speed that the eye can readily follow. Fine adjustment of the speed will bring the beats down to one every two seconds or slower.

Having paralleled the alternators, if one tends to run faster than the other the slight difference in phase will cause current to flow between the alternators in such a direction as to correct the tendency, and the machines should be quite stable, dependent only upon the performance of their engine governors.

Synchronizing with Transformers. There is a dislike of synchronizing with dark lamps, in case one of them should break down and give a false indication, and also considerable judgement is required to determine the middle of the dark period. Consequently, with low-voltage single-phase alternators, the lamps may be coupled across opposite sides of the paralleling switch, so that the "in-phase" condition is indicated by the lamps being at full brilliancy.

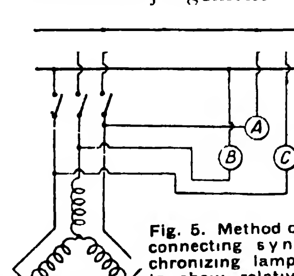
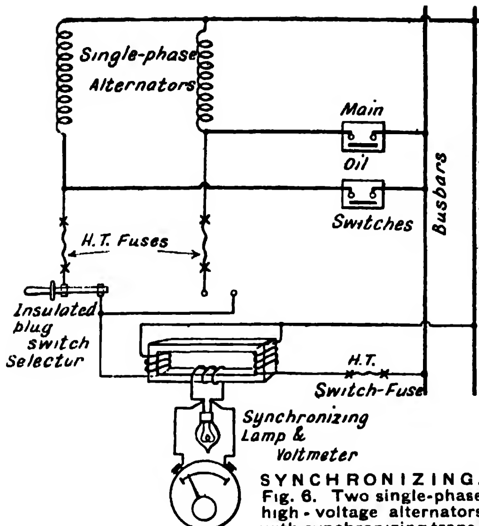


Fig. 5. Method of connecting synchronizing lamps to show relative speeds—three-phase, low voltage.

Moreover, most alternators are high-voltage machines, and quite a number of lamps would be required in series. The usual potential transformers (*q.v.*) can be used, and are so employed with the instruments that have been more recently developed to indicate synchronism, as described under Synchroscope.

An intermediate expedient, still infrequently used, is a separate synchronizing transformer, with windings on separate limbs fed from the bus-bars and the incoming machine respectively; a third



SYNCHRONIZING. Fig. 6. Two single-phase high-voltage alternators with synchronizing transformer, lamp and voltmeter.

winding supplies a lamp and/or a deadbeat voltmeter. According to whether the main windings are of the same polarity or in opposition the flux is non-existent or a maximum when the two voltages are in phase, and thus either dark or bright lamp synchronizing can be arranged. If a voltmeter is used, and it is desired to synchronize with full deflection, the polarity of the two windings must be additive.

The drawback of this device, as operated in the past, was the necessity for selective high-tension switching for the connexion of the transformer on to the incoming machine. The same idea can be used with low secondary voltages derived from potential transformers, but when these are available, as is now normal practice, it is better to use a rotary or similar synchroscope.

Indications for the synchronizing of polyphase alternators are obtained only on one phase, the others being necessarily in correct relation thereto by the construction of the machines. It is possible with three-phase (not single-phase) alternators to connect synchronizing lamps in such a way that they light up in sequence and so indicate whether the incoming machine is running fast or slow. As shown in Fig. 5, lamp A is connected as for ordinary dark synchronizing, while B and C are reversed. When the speed is low B lights up when A is dim, then A lights fully while B goes out, and C follows in sequence, so that the light appears to travel clockwise. With higher speed the rotation is reversed. Synchronization is indicated by A dark, and B and C dim.

Use of Instruments. Since most alternators are three-phase high-voltage machines, practical synchronizing is chiefly done with instruments connected to the standard 110 volts on the secondaries of potential transformers. The three-phase rotating light device would necessitate three transformers for each machine, whereas only one is usual and suffices for the ordinary synchroscope, which gives the same indication of relative speed. Four-pin plug switches are commonly used for selecting purposes on the secondary sides of the potential transformers, and the latter may also be used for the voltmeters and other equipment within their capacity.

Automatic Synchronizing. Automatic synchronizing is quite possible, but not yet common except in the case of rotary converters and similar plant. These, however, are frequently connected to the supply while they are out of phase, with some form of inherent or external reactance in series to limit the current. They pull in to synchronism without being actually switched in at the correct moment as is generally implied by the term synchronizing. Firms such as Brown-Boveri Co., Ltd., and A. Reyrolle & Co., Ltd., have, however, developed appliances for synchronizing by automatically operating switches as would be done manually, and these may become more common in the future. The equipment of the first-mentioned firm is similar in general construction to its well-known automatic voltage regulator; while that of the second firm relies entirely upon relays, actuated or locked out by the resultant voltages between the machines as the phases change.

SYNCHRONOUS CONDENSER. To overcome the ill effects of lagging currents, attention has been given to methods of introducing into the distribution system itself leading currents which, when combined with the lagging currents, shall bring the power factor of the whole to unity value.

For this purpose well-loaded synchronous A.C. motors are frequently used and

are also known as phase advancers (*q.v.*). Such a motor is necessarily separately excited, and the phase-angle of the current it takes depends upon the excitation. At normal excitation the phase-angle should be zero and the power factor of the machine unity. If under-excited the motor takes lagging currents and if over-excited leading currents. The most economical effect is produced when the motor can be well loaded mechanically, this marking an important advantage over the use of static condensers. The motor, if it is to give large out-of-phase currents, must be larger than if it is to run at unity power factor, but a large motor can be designed to give a leading wattless current 60 per cent. of its kVA rating at an increase of less than 10 per cent. in its cost. Such a current corresponds to a leading power factor of 0·8. The subject is further considered under the heading Condenser and Synchronous Machine. *See also* Phase Modifier.

SYNCHRONOUS CONVERTER. An electro-magnetic machine for converting alternating current of a given frequency to direct current or direct current to alternating current.

There are two main types of synchronous converter, the rotary converter and the motor converter, which are fully described under the heading Converter.

There used to be no other methods of converting from A.C. to D.C., but in recent years mercury arc rectifiers (*q.v.*) and other types of vapour and gasfilled valves have been used for the same purpose. *See* Rectifier.

SYNCHRONOUS MACHINE. An alternating current generator or motor that runs at a speed exactly proportional to the frequency of the system to which it is connected. Alternating current machines are either synchronous or asynchronous (*see* Asynchronous Machine).

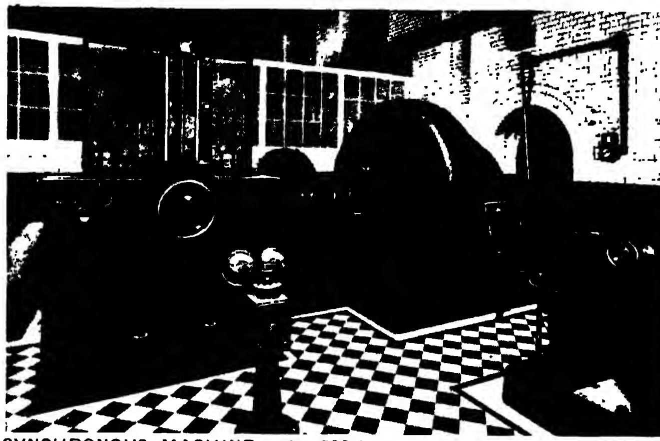
A synchronous generator is usually called an alternator, and the method of operation is described in detail under the heading Alternator. An alternator in its simplest form consists of a coil which is brought alternately under the influence of the north and south poles of a magnet. Usually the coil is stationary and the magnet is mounted on a moving wheel or rotor. If there is one pair of poles, north and south, on the rotor the voltage induced in the stationary coil passes through one complete cycle for each revolution of the rotor. The number of cycles per second or frequency is therefore equal to the number of revolutions of the rotor per second. If there are two pairs of poles the number of cycles per second is doubled. For N pairs of poles the frequency is N times the revolutions per second.

The speed of machines is usually expressed in revolutions per minute, and the frequency in cycles per second for N pairs of poles is N times the revolutions per minute divided by 60. For a frequency of 50 cycles a two-pole machine must run at 50 revolutions per second or 3,000 revolutions per minute. For N pairs of poles the speed will be 3,000 divided by N.

Alternators are usually driven by steam turbines which operate most efficiently at high speeds. Two- or four-pole machines are therefore used having speeds of 3,000 and 1,500 r.p.m. respectively. Before the development of steam turbines slow moving reciprocating steam or gas engines were used having about one-tenth the above speeds and machines having 20 or 40 poles were quite common. Such machines are not often encountered in modern practice.

Alternators are almost invariably provided with three sets of coils on the stator connected so as to give a three-phase supply. The current in the windings produces a magnetic field which rotates at the same speed as the rotor. The rotor is therefore provided with a heavy winding through which direct current is circulated to counteract the magnetic field produced by the stator coils. At low lagging power factors the stator field is almost in direct opposition to the rotor field and the current supplied to the rotor windings has therefore to be increased (*see* Field Regulator). If a leading current is supplied by the alternator the field current has to be correspondingly decreased.

If a synchronous machine has its terminals short-circuited a current of ten to twenty times the maximum output of the machine flows for a few cycles and subsides in about $\frac{1}{4}$ second to two or three times the maximum output as the



SYNCHRONOUS MACHINE. An 800-h.p. induction motor driving flour return of a large mill through belt and shafting.
G E C, Ltd, of England.

magnetization of the rotor is counteracted by the heavy wattless current in the stator (*see* Short Circuit). The switchgear connected to alternators of large maximum output has therefore to be able to control very heavy currents.

Synchronous Motors. These are constructed like alternators. They usually run at a speed of about 750 r.p.m. The number of pairs of poles for this speed is $\frac{3000}{750} = 4$ pairs. The rotors are usually of the salient pole type (*see* Field Magnet). To put a synchronous motor on load it has first to be run up to speed either by means of a separate motor of the induction type or by means of special windings which enable it to behave as an induction motor (*q.v.*) itself during starting. The field excitation is adjusted to give the correct voltage and the speed of the machine and the phase of the voltage are checked by means of a synchroscope (*q.v.*). The process of synchronizing is exactly similar to that of synchronizing an alternator.

If the excitation is adjusted so as to give exactly the correct voltage before switching in, the motor will take a current after switching in of just sufficient value to keep it rotating. If the excitation is then increased a demagnetizing or leading current will flow in from the supply system. This has the effect of improving the power factor. Synchronous motors are frequently used for the sole purpose of power factor improvement. When used for this purpose they are termed synchronous condensers (*q.v.*).

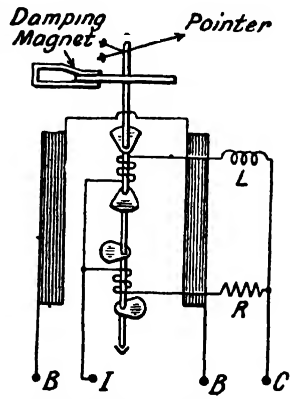
They can also be used for the combined purposes of power factor improvement and mechanical drive. The machines used for this purpose resemble wound rotor induction motors (*see* Induction Motors). They are run up to speed as induction motors and a supply of direct current is then switched on to the rotor windings. The rotor then runs at synchronous speed and by increasing the amount of direct current supplied the motor can be made to take leading current. Motors of this type are used for heavy drives. They are not suitable for light drives because they require an exciter and special starting arrangements. It is not possible to control the speed of synchronous motors. Their use is therefore restricted to constant speed drives such as for line shafting in factories or for large fans and pumps running against a fairly constant head of air or water. It is not usual to use synchronous motors for light drives except where synchronism is essential, as in the case of electric clock motors (*see* Clock, Electric). *See also* Scherbius Machine.

SYNCHROSCOPE. An instrument, the pointer of which indicates the difference or coincidence of phase between two A.C. voltages, and also the approximate rate of approach to or departure from the coincident state; used to enable alternators or A.C. systems to be connected in parallel without disturbances.

Synchroscopes usually have a pointer movable through 360° over a scale blank except for a mark in the top vertical position, indicating synchronism. Some have a double-ended pointer indicating synchronism in the vertical position.

Electrically, the movement is a special form of phase meter, similar to a power factor meter. There are two elements, one or both stationary according to the design, fed from the two voltages, the phase relation of which is required to be shown. The elements are arranged so

that when there is no phase difference between the magnetic fields produced by them the pointer is upright. Any steady difference in phase causes the pointer to take up a different position, and a progressive alteration in the phase relation causes rotation in one direction or the other, depending upon whether the incoming supply is gaining or losing time in relation to the other. The interval between two consecutive "in phase" conditions corresponds to one complete revolution of the pointer, which thus shows the state of affairs much more precisely than ordinary synchronizing lamps (*see* Synchronizing).

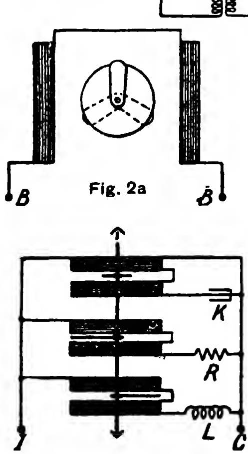


SYNCHROSCOPE. Fig. 1. Diagram of connexions of Nalder Bros., Ltd., instrument.

Inductor Types. In the N.C.S. (Nalder Bros. & Thompson, Ltd.) synchroscope stationary field coils are coupled across the bus-bar or other reference voltage. The moving system comprises four shaped pieces of iron arranged on a shaft so as to be magnetized by two stationary coils, which latter are fed in series respectively with a resistance and inductance, so producing out-of-phase fluxes. An eddy current brake disc is also mounted on the shaft. By proper positioning of the iron inductors a steady rotation is secured and the in-phase relation is definitely shown by the vertical position of the pointer on the shaft.

Everett, Edgcumbe & Co., Ltd., employ a three-phase inductor, the separate irons being arranged between duplicate stationary coils, one each in series with a condenser, resistance and inductance. A pair of stationary field coils connected to the bus-bar supply acts as the reference, to which the fluxes produced on the inductors react so that the steady in-phase condition gives a stationary vertical position of the pointer, any steady condition of out-of-phase relationship gives a corresponding deflection, and a continuous variation of the two fluxes gives rotation.

Dynamometer Type. A different principle is employed in the Weston synchroscope, which is an instrument of the dynamometer type (*q.v.*). Stationary field coils (split into two) are coupled to the bus-bar supply, while a movable light coil is connected through slip-rings to the incoming supply. When the two fluxes coincide in phase there is no torque and the pointer is gravity controlled to take up a vertical position. Any departure from phase coincidence causes the moving coil to rotate correspondingly and thus to deflect the pointer. The pointer is also vertical for the 180° out-of-phase condition, and hence a further device is necessary to eliminate any misunderstanding. This is achieved by mounting the pointer behind an opalescent glass and by the provision of a bright synchronizing lamp



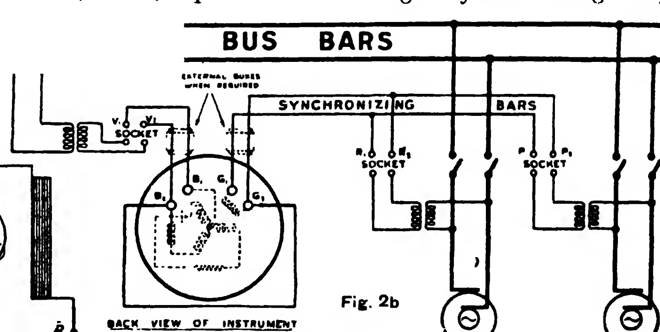
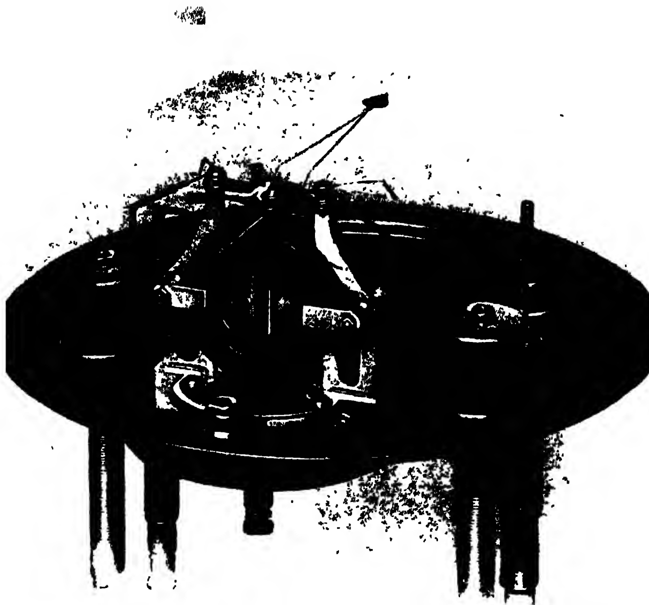
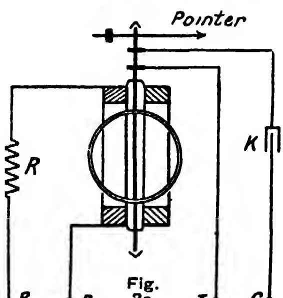


Fig. 2a (left). Arrangement of Everett Edgcumbe synchroscope. Fig. 2b (above). Two generators connected up with voltage transformers for use with this instrument.

Courtesy Everett, Edgcumbe & Co., Ltd.

to throw the shadow of the pointer on the glass. When, therefore, the incoming supply is steadily gaining or losing compared with the bus-bar supply, the pointer moves from side to side but is only





SYNCHROSCOPE. Fig. 3a (left). Connexions of the Weston instrument

Fig. 3b (above). Dismantled view of the instrument.
Courtesy Weston Electrical Instrument Co., Ltd.

illuminated when passing in one direction, *i.e.* when the two supplies are properly in phase. The pointer thus appears to be rotating, whereas it is really only oscillating.

All synchroscopes can be fitted with additional red and green signal lamps to indicate at a distance whether the incoming set is running fast or slow. All, moreover, are designed for relatively short-period use and will overheat if left on circuit indefinitely. For this reason, and in order to permit one equipment to serve for a number of alternators, they are invariably connected up through plugs and sockets. In important plants, duplicate synchroscopes are provided, and in every case there should be some alternative equipment, although these instruments are very reliable. *See* Synchronizing.

SYNTHETIC RESIN. A group name applied to any resinous substance prepared artificially by a chemical process as distinct from one derived from natural sources.

Synthetic resins were first prepared commercially by Dr. Baekeland by the reaction of phenol (of which commercial carbolic acid is an impure form) and formaldehyde (of which formalin is a 30–40 per cent. solution) in the presence of a condensing agent. Resins prepared by this and similar processes, and the analogous resins prepared from the three isomers of cresol (*o*, *m*, and *p*), either alone or in combination, are known as phenol-formaldehyde resins, or Bakelite resins. These still form the most important group of synthetic resins used in the electrical and allied industries.

By varying the raw materials employed and their proportions, the condensing agent, which may be either acid (*e.g.* sulphuric acid) or basic (*e.g.* ammonia), and the temperatures and pressures employed during manufacture, resins with different properties and suitable for different purposes may be produced.

One property possessed by some, though not all, synthetic resins, and one not shared by natural resins, is that of thermo-hardening, or thermo-setting. But for this property it is extremely unlikely that the synthetic resin industry would hold its present important position.

Thermo-hardening. Bakelite resins may exist in any one of three forms, known as the A, B, and C stage respectively. In the A stage, they are either viscous liquids or solid resins soluble in certain organic solvents, such as methylated spirit. In this stage they may be used in the manufacture of spirit varnishes, bonds and cements (*e.g.* the cement used for bonding the cap and bulb of electric lamps), and for the preparation of moulding powders, in combination with suitable fillers.

When heated above a certain minimum temperature for a time that depends on the resin and the actual curing temperature, it passes into the B stage, when it is

no longer soluble, but is still fusible. On further heating it passes into the final, or C, stage, when it is no longer fusible or soluble. This property is the basis of the bakelite moulding industry (*see* Bakelite; Plastics), and is also utilized in the production of laminated insulated panels, cylinders, and tubes and similar operations.

Phenol-formaldehyde resins are not soluble in drying oils (linseed, tung oil, etc.), but only in spirits. As explained elsewhere, spirit varnishes give rise to brittle films and should not be used for impregnating windings that are likely to be subjected to wide variations of temperature.

Oil soluble resins may be obtained by fusing phenol-formaldehyde resins with natural resins. An important class of these modified synthetics are marketed under the trade name of "Albertols"; some of these are suitable for the production of impregnating varnishes, whereas others are suitable for the production of enamels and stoving lacquers for finishing electrical products and machinery.

Urea- and thio-urea formaldehyde resins form a closely similar group, of which "Beatl-ware" is a commercial application.

Glyptals form another class of synthetic resin, more recent in development, but rapidly becoming of importance. The original glyptals were produced by the reaction of phthallic anhydride on glycerin. Glyptals are thermo-hardening, but their curing time is much longer than that of the phenol-formaldehyde resins, hence they have not found the same application in the production of moulded articles, though there are indications that before long the curing time may be substantially reduced. At present glyptals find their chief use in the manufacture of quick-drying high-gloss paints and enamels, which are petrol and oil-proof, and in the production of stoving lacquers. As these latter are capable of withstanding high temperatures they are suitable for finishing heating apparatus, including cookers, where they may in time replace vitreous enamel.

Cumarone resins formed by the action of sulphuric acid on rectified wood naphtha also find important applications in the preparation of quick-drying paints and enamels.

Other types of synthetic resins are produced besides the above (*e.g.* vinyl, furfural and other aldehyde resins), but at present are not of sufficient interest to the electrical industry to include here.

TACHOMETRIC ELECTROMETER. A form of electrometer (*q.v.*) for the measurement of extremely small currents. The needle is kept at a fixed reading by means of a contact mechanism driven by a variable speed motor, which periodically charges the vanes from a small condenser and thereby compensates for the loss in charge. Observation of the speed of the motor affords indication of the current quantities.

T AERIAL. An aerial whose down lead joins at the centre of the horizontal span, or at any other point thereon except at the end, when the aerial would be an inverted L aerial. The last mentioned type is the best, because if the down lead is not central, out-of-balance effects may be set up owing to the aerial responding to two different natural frequencies corresponding to the longer and shorter span lengths. These T aerials are used in all modern broadcasting stations because they provide the lowest directional effects of any aerial system. *See* Aerial; L Type Aerial.

TALKING FILM. *See* Sound Film Plant.

TANGENT. The ratio of the perpendicular to the base in a right-angled triangle is known as the tangent of the angle between the base and the hypotenuse. The slope of a curve is always represented by the ratio of the ordinate to the abscissa at the point considered which is the tangent of the angle made by the curve to the horizontal at that point. *See* Cosine; Sine, *etc.*

TANGENT GALVANOMETER. Variety of galvanometer. It is so called because the strength of the current passed through its coil is proportional to the tangent of the angle of deflection of the magnetic needle in the centre of the coil. The scale of the tangent galvanometer is therefore a tangent scale.

Essentially the tangent galvanometer

consists of a circular coil of a few turns of insulated wire with a small magnetic needle suspended at the centre. A light aluminium pointer is attached to the needle and enables the deflection to be read on a horizontal scale graduated in degrees. The needle is small enough to justify the assumption that the magnetic field due to the current in the coil is uniform throughout the space occupied by the needle and equal to the field at the centre of the coil.

The coil is set in the magnetic meridian so that the needle and the coil are in the same plane. The current is then passed through the coil, and the angle of deflection read off from the scale. If the angle of deflection is θ, and I the current in absolute units, then $I = 10\ K \tan \theta$ ampères, where K is a constant known as the reduction factor of the galvanometer. *See* Galvanometer.

TANGENT SCALE. Since the current in a tangent galvanometer is proportional to the tangent of the angle of deflection, the circular scale over which the pointer moves must be also graduated to read directly according to the tangent of the angle of deflection, and the instrument is then said to have a tangent scale.

TANNERIES, ELECTRICITY IN. Electricity is used in tanneries and leather-dressing establishments for driving a large number of machines which, though taking little power individually, may require anything up to 1,000 h.p. in the aggregate, and for lighting purposes, "daylight" lamps or luminous tubing being required for grading the skins.

Electric motors can drive liquor production and handling plant (*e.g.* crushing mills, breakers, grinders, presses, conveyers and pumps), skin preparing and tanning plant (*e.g.* painting machines, paddles, fleshers, washers, revolving drums or tumblers for tanning, dyeing, etc., and drying fans), finishing plant (*e.g.* glazing, staking, setting, seasoning, shaving machines, etc., and air compressors for spray guns), measuring machines, and de-greasing plant. These are usually driven in groups from slip-ring motors, ample power should be provided to allow for the intermittent loads on the drums. The corrosive vapours and gases in the wet departments make the use of totally enclosed or frame-cooled motors desirable, and the windings should be treated with an acid-resisting compound; the motors are often mounted a foot or two above the ground level to prevent the possibility of flooding by overflows of liquor.

Wiring should be carried out with tough-rubber-sheathed cable mounted on cleats and all fittings should be watertight and have their casings efficiently earthed.

POWER REQUIRED FOR DRIVING TYPICAL TANNERY MACHINERY

Description	Size of motor h.p.
Bark mills	3–6
Bark grinders	6–10
Crushers	1–3
Presses	1–3
Fleshing machines . . .	8
Washers	1
Paddles	2
Revolving drums . . .	4–6
Measuring machines . .	$\frac{1}{4}$
Finishing machines . .	$\frac{1}{2}$–5
Air compressors for spray guns	1
Shaving and scouring machines	2–3

TANTALUM LAMP. Formerly employed in place of the carbon filament lamp on account of its lower specific consumption but now entirely superseded by the tungsten lamp. *See* Filament; Lamp; Metal Filament Lamp.

TAP-CHANGER. A switch or contactor for changing over to different tappings on a transformer or auto-transformer. *See* Transformer.

TAP-CHANGING TRANSFORMER. *See* Transformer.

TAPPINGS. Connexions to some source of E.M.F. whereby a portion is by-passed or utilized. In the case of a transformer, for example, different voltages may be obtained by connexions to intermediate points in the primary or secondary winding. Similarly tappings from armature windings to slip-rings afford means of varying rotor resistance for speed control or other purposes. *See* Transformer.

TARIFF. The manner in which the consumer makes his demand upon the supply station has an important effect upon the cost at which electrical energy may be

produced. The cost of production is made up of two main charges—capital charge and running costs—and a consumer who demands a small current continuously over a comparatively long period will evidently necessitate less capital expenditure on plant at the station than one who, taking the same total in the same time, demands a large current for a short time.

The ways in which the charges to different classes of demand are adjusted vary greatly in different localities and under the direction of different chief engineers. Thus the flat rate tariff, in which a price is charged according to a single condition, such as the number of units metered or the maximum demand, and which constitutes the simplest economical scheme in paying a fixed price for a fixed supply, is usually displaced by the more favourable two-part or two-rate tariffs. In the former scheme of charging, concessions are made to the large consumer by having a fixed charge based on a characteristic of the service (*e.g.* the maximum demand, or rateable value), with an additional but considerably reduced charge for each unit consumed.

In the two-rate tariff a discrimination is made in the tariff rate for two periods of the day, to encourage the consumer to adopt certain hours of the day when light load occurs for such purposes as water heating, etc., and thereby improving the diversity factor of the load on the power station. Similarly a seasonal rate tariff affords discrimination in the tariff rate for different seasons of the year. *See also* Contract Rate; Flat-Rate; Maximum Demand; Two-part Tariff, *etc.*

TECHNICAL TRAINING FOR ELECTRICAL ENGINEERS

By Philip Kemp, M.Sc., M.I.E.E., A.I.Mech.E.
Head of the Polytechnic School of Engineering.

This short résumé of the two main types of training courses outlines the principles of training of students in electrical engineering by full-time University and College three-year courses, and by the five-year courses in evening study. Consult also the introductory essay in this volume by the same author. See Institution of Electrical Engineers ; National Certificates and Diplomas.

The technical training of a young man preparing for the engineering profession should not be conceived on narrow specialist lines, but should rather embody a broad course of study of scientific and engineering principles. Specialization should be deferred until after these general principles have been mastered. The whole subject is continually growing in ever-widening directions, and it is an impossible task, even for the best of students, to acquire a full knowledge of all branches of engineering practice. If he intends to become a technically trained electrical engineer, he should endeavour to gain some knowledge of the general principles of physics and chemistry, together with the all-important subject of mathematics. Linked up with these are mechanics and engineering machine drawing.

It is highly desirable that a preliminary knowledge of some or all of these subjects should be gained at school, before entering on his engineering studies, as otherwise he will be to some extent handicapped. This is a point that is not always appreciated. There is usually some choice in the subjects for the matriculation or school certificate examination, and if subjects other than those enumerated above are selected, then extra time or effort will be needed before the student can do himself justice.

First Year College Course. The usual full-time engineering course at a University or Technical College covers a period of three years, the standard of entrance being normally that of matriculation or general school certificate. Students of all branches of engineering are usually grouped together in the first year of their course, and it is general practice to give exactly the same course (slight modifications occur in individual colleges) to civil, mechanical, and electrical engineering students. This course will include a generous allowance of mathematics, of the practical or applied, rather than of the so-called pure type. Mechanics also will be dealt with in considerable detail.

It is rather a difficult matter to say

TECHNICAL TRAINING. The training workshop of the British Thomson-Houston Co., Ltd., in which student apprentices receive their technical training.

where applied mathematics ends and practical mechanics begins; the two subjects merge imperceptibly into one another. From mechanics to engineering drawing, involving a knowledge of machine parts, is an obvious step, and a considerable part of a first year student's course should be spent in the college drawing office. Here he must acquire some degree of skill in actual manipulation, for which time and practice are essential. Physics and chemistry, together with appropriate instruction in the respective laboratories, are also essential subjects, and it is in the former that the electrical engineering student receives his first instruction in electrical matters, when studying the fundamental subject of electricity and magnetism. No technical electrical engineering is studied at all in the first year, and it is quite common practice for an electrical engineering student never to enter the electrical engineering department of his college at all during the first year of his course.

Extra subjects, such as a foreign language, may be introduced into his course, but in very many cases these are excluded, not because they are undesirable, but because they do not contribute directly towards an engineering training, and because it is impossible to include everything in view of the limited time at disposal. So far, students of all branches of engineering have undergone a common course of instruction, no difference being made at all between electrical and mechanical engineering students.

The Second Year. In the second year of his course, the electrical engineering student will begin to study his own subject from a technical standpoint. He will still continue his study of mathematics and mechanical engineering subjects; possibly also physics and chemistry, but about one-third of his time will now be devoted to technical electrical engineering subjects. He will be introduced to the principles governing the operation of electrical machinery and apparatus, starting with direct current work, followed almost immediately by a study of the alternating current circuit.

From now onwards a greater and greater proportion of his time will be spent in the study of alternating current problems, since the great bulk of electrical engineering practice is to-day associated with the alternating current system. The student will also, at this stage, be introduced to the methods of construction adopted in manufacturing practice, and his work in the drawing office will begin to take on an electrical engineering bias.

A portion of his time will also be spent in the electrical engineering laboratories, where he will make actual contact with the machines and apparatus of which he has heard descriptions in the lecture theatre. The importance of this laboratory work cannot be over-estimated. It is really the life-blood of the course, and consolidates the work of the lecture theatre and class room. It makes things real to the student which otherwise would be merely hearsay, and experience has shown the immense value of the experimental part of the course.

The Third Year. Much more of his time is now spent in the electrical engineering department itself, a common arrangement being to divide his time in the ratio of two-thirds to electrical engineering subjects and one-third to mechanical engineering subjects and mathematics. The

study of the latter should be continued throughout the whole of his course, in spite of the fact that the advantages of this policy may not be immediately apparent to the student himself. Mathematics in itself forms such a valuable mental training that, apart from its engineering application, its study should be prosecuted if for no other reason than to train the student into orderly ways of thinking. The technical side of certain branches of electrical engineering are very mathematical in their character, as, for example, high frequency and radio engineering, and without the proper mathematical equipment a student finds it exceedingly difficult, if not impossible, to acquire more than a superficial knowledge of the subject.

During his final year the student will spend an increasing proportion of his time on alternating current problems, since he will now be concerned with generation, transmission and distribution of electrical power, and this is now almost entirely alternating current, at any rate so far as the first two items are concerned. He will also be introduced to the subject of electrical machine design. Such a course is of great value, quite apart from the fact that the student may not be contemplating going on to this kind of work in actual practice. The study of the principles of electrical machine design forms one of the best ways of learning the behaviour and characteristics of the various types of machine dealt with, and gives the student a clearer insight into their manner of operation.

High-frequency engineering should by no means be neglected, even if the student intends to devote himself to the heavier side of the industry. There are now so many applications of high-frequency engineering that no electrical engineering student can afford to be ignorant of this side of the work. Indeed, the thermionic valve has invaded so many fields that it can now no longer be regarded as having relation to wireless and high-frequency work. The subject of electrical measurements is also of great importance, and its range is now so wide that it may be regarded as a separate subject of study in itself.

In the purely mechanical engineering subjects, the electrical engineering student should study the properties and strength of materials, theory of machines, heat engines, and hydraulics. If he contemplates entering the supply side of the industry, the value of a knowledge of the theory of heat engines will be at once apparent, whilst hydraulics is scarcely less important. In fact, it is of paramount importance in connexion with hydro-electric power schemes.

Evening Study Courses. In an evening course of study the range of subjects is naturally somewhat narrower in view of the more limited time at the disposal of the student, but roughly speaking the first year of the evening course will correspond to the first year of the full-time day course, except that it will not cover the same range of subjects, whilst the second and third years of the evening course will correspond roughly to the second year of the full-time day course. Similarly, the fourth and fifth years of the evening course correspond to the third year of the day course. There is a tendency for evening courses to specialize rather more than in day courses, so that in certain directions a student will gain a more detailed knowledge of a particular subject, but he will not have the advantage of the wide range enjoyed by his more fortunate brother who is enabled to spend his full time at his studies.

Homework consisting of set exercises and also of private reading is a necessary adjunct to a course of study as set out above. The regular working of examples and answering of questions is of great help to the student, inasmuch as it helps him to find out those things which he does not understand, and if he has any acumen he will be able to rectify his faults. The rightful use of text-books is also a question of great importance. The private study of text-books in itself cannot replace actual tuition, but it can and does act as a very valuable supplementary aid. After a student has received a lecture on a particular subject he should endeavour to read up the same subject in his text-book as soon after as possible, before his recollection begins to fade. The judicious asking of questions by him will then in the majority of cases enable him to acquire a proper knowledge of this particular item.

Examinations. The question of examinations is a very vexed one. It is the general consensus of opinion that examinations cannot be dispensed with entirely, but certain people hold the view that there is rather too much of them. The argument is advanced that the teaching staff are just as competent to judge a student from his ordinary work, day by day, as they are from the results of an examination covering only a few hours. There is a great deal of truth in this, but the system is open to abuse. Again, it is undoubtedly a fact that, human nature being what it is, the average student works harder if he is confronted with an examination at the end of his course. It provides an incentive, and although there are without doubt exceptions, it would appear that the examination system is the lesser of two evils.

The following gives a typical syllabus for a full-time course covering three years, and reaching a standard which is approximately that of the B.Sc. of London University.

	Hours per week
FIRST YEAR	
Mathematics	6
Mechanics	3
Physics	4
Chemistry	4
Engineering Drawing	7
Engineering Workshop and Laboratory	6
SECOND YEAR	
Mathematics	5
Strength of Materials	1
Theory of Machines	1
Heat Engines	1
Hydraulics	1
Engineering Workshop and Laboratory	5
Engineering Drawing and Design	3
Physics	2
Chemistry	2
Electrical Technology	6
Electrical Drawing and Design	3
THIRD YEAR	
Mathematics	5
Strength of Materials	1
Heat Engines	1
Engineering Laboratory	3
Alternating Current Technology	4
Generation, Transmission and Distribution	2
Utilization of Electrical Energy	2
Wireless and High Frequency Engineering	2
Electrical Machine Design	4
Electrical Engineering Laboratory	6

The above syllabus must not, of course, be regarded as other than an average one, and some departure from it will be observed in almost every college, but it may be taken as giving a general indication of what may be expected in a normal case.

TELAUTOGRAPHY. Alternative name for Photo-telegraphy, *which see.*

TELECTOGRAPH. A system of photo-telegraphy in which a metal stylus traverses a metal base original, and transmits currents varying in intensity with depth of tone of the original. Chemically prepared paper transforms current impulses into reproduction of original at receiving end. This system has been largely superseded by the methods described under Photo-telegraphy (*q.v.*).

TELEPHONE (In Radio). Although head telephones are now very little used in the reception of broadcasting their use is extensive in other spheres of radio-communication, for example, in the reception of wireless messages on board ship, in aeroplanes, etc.

The type of telephone receiver most suitable depends on the nature of the received signals, for instance, whether speech or Morse signals. For receiving speech the ordinary flat diaphragm ear-piece is commonly used, as it gives a sufficiently even response over the range of speech frequencies to keep distortion within reasonable limits. The same type is used for Morse signals where various musical frequencies are involved, as in spark transmissions from ships.

In the beat reception of continuous wave telegraphy the heterodyne note can be given any desired pitch and for this reason telephones with a marked resonance at a particular frequency can be used. The heterodyne note is adjusted until maximum signal strength is obtained in the telephones. By this means extreme sensitivity is obtained. Telephones embodying this feature are usually of the tuned reed type. A sprung iron reed is attached to the centre of a conical aluminium diaphragm and actuated by the magnetic variations due to the signal currents. These telephones are much more sensitive than the diaphragm type although not so robust mechanically.

Both types referred to are polarized by a permanent magnet in each ear-piece, the signal currents producing variations of the magnetic field which in turn result in variations in the magnetic pull on the diaphragm or reed.

TELEVISION: THE PRINCIPLES EXPLAINED

By S. O. Pearson, B.Sc., A.M.I.E.E.

Since television has passed out of the purely experimental stage an examination of its principles and the most promising methods is of importance to the student. Here those methods which have been most successful in practice are explained, including disc scanning, the mirror drum method and the cathode ray. See Cathode Ray ; Kerr Effect ; Light Relay ; Photo-Electric Cell.

Television constitutes the transmission and reception of moving pictures or scenes by electrical methods. Though the technical and practical problems involved have been many and difficult, developments have proceeded so rapidly that television has now become a practical reality of definite entertainment value, and public services already operate in several countries. Although excellent results have been obtained under laboratory conditions for some time past, the apparatus required for reception was much too complicated and expensive to warrant a permanent television service. Recent developments, however, have shown new possibilities for the simplification of receiving apparatus. Present indications are that the transmission of moving pictures will take its place as a companion service to the now national institution of broadcasting, and that continuous improvements will be made both in transmission and reception on parallel lines to the perfection of the broadcasting of sound from the crystal set stage to the highly efficient and satisfactory performance of the modern transmitter and multi-valve receiver.

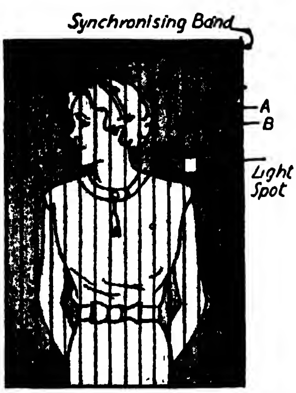
Basic Principles. It is common knowledge that a cinematograph picture thrown on the screen is not actually moving continuously, but consists of a rapid succession of stationary pictures, each one slightly different from the preceding one. An impression on the retina of the eye persists for a fraction of a second after the actual image has disappeared, and so, providing the pictures projected from the film follow one another in sufficiently rapid succession, the retentivity of the eye leads to the impression that the picture is actually moving continuously, and no flicker is evident. There must be at least 10 pictures per second to give the apparent effect of continuous motion, but if flickering is to be avoided altogether, more than 20 pictures per second are necessary. In standard cinema apparatus the rate of projection is about 24 pictures per second.

In television the same conditions apply as regards the number of complete pictures that must be transmitted per second ; but each individual picture has to be transmitted in the form of electrical impulses, and so it is not possible to transmit a complete picture instantaneously. It is necessary to divide the picture into a large number of small areas each with a depth of shade according to its position in the complete picture. By a suitable optical or mechanical system in conjunction with a light-sensitive cell these small areas or " elements " of the picture are made to transmit individually and in succession electrical impulses of intensity depending on their depth of shade, the whole picture being covered bit by bit in this way in at most one-tenth of a second. The process is called " scanning." At the receiving end the electrical impulses are made to reproduce the small areas of light and shade on a screen in their correct relative positions and so to reassemble the picture.

The Photo-Cell. Before considering methods of scanning, a brief description of the light-sensitive cell is necessary. The function of this is to convert variations of light intensity into corresponding variations of electric current in much the same way that a microphone converts sound vibrations into electrical variations. Although the properties of selenium were made use of in the earliest television experiments, it was found that a time lag existed between the light variations and the resulting changes of resistance. So in modern systems the light-sensitive device invariably consists of a photo-electric cell or photo-cell, which is entirely free from time lag. It is an electronic device, consisting of an evacuated bulb containing a cathode and anode, like a thermionic valve. The cathode is coated with a light-sensitive substance which has the peculiar property of emitting electrons

to an extent depending on the amount of light falling on it. Among such substances are caesium, rubidium and potassium, their relative light-sensitivity being in the order given. Caesium is about five times as sensitive as rubidium and twenty-five times as sensitive as potassium. (*See also* Caesium Cell *and* Photo-Electric Cell.)

Principles of Scanning. Although there are a number of methods of scanning the televised picture, they are practically all based on the same principle whereby the picture is divided into parallel strips, as in Fig. 1, the light from the picture elements forming the first strip A being made to affect the photo-cell in succession from one end of the strip to the other. Then the process is repeated for the next adjacent strip B, and so on until the whole picture has been covered or scanned. And the complete process must take place in not more than one-tenth of a second.



TELEVISION. Fig. 1. Line scanning. A light-spot passes from top to bottom, or vice-versa, along the successive strips.

The details of the scanning process are most easily understood by the consideration of one of the simplest systems and the first to prove successful in practice. This refers to the scanning disc or Nipkow disc method which has been used in the Baird system in this country until quite recently. It consists essentially of viewing the picture through square holes in a rotating disc, the holes being in a spiral line, as indicated in Fig. 2. For simplicity the picture can in the first place be considered as a transparent film, light being passed through it from a suitable source. The disc is situated between the film and the photo-cell, and the only light which can reach the latter is that coming through one of the holes opposite the picture. The holes are so spaced that only one occurs opposite the picture at any instant and each passes across a different strip of the picture.

As a particular hole moves across the film the light passing through varies in conformity with the variations of density of the picture in the strip covered, and the photo-cell converts these light variations into electrical impulses. The next succeeding hole in the disc covers an adjacent strip, and so on until the whole picture has been covered or scanned. With a single set of holes in the disc the picture is completely scanned once every revolution of the disc, and if the picture is a moving one each complete scan covers a slightly different picture from the preceding one, and somewhat the same effect is obtained as in a cinema picture, except that each individual picture is transmitted not as a whole but as a large number of small elements, not simultaneously but successively.

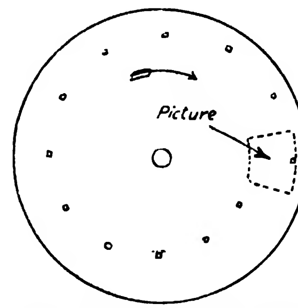
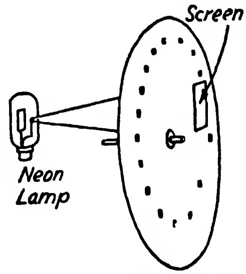


Fig. 2. The Nipkow scanning disc. With this method the scanning lines are arcs of circles.

The electrical impulses from the photo-cell are amplified and transmitted to the receiving apparatus by radio or by wire and, except for the different frequency range involved, the same principles of transmission and reception are used as for sound broadcasting.

The Receiver. At the receiving end, in the simple system under consideration, the received electrical variations are amplified and made to vary the intensity of a source of light. An ordinary lamp is not suitable on account of its large thermal inertia and a neon lamp is usually employed. The lamp is connected in the anode circuit of the output valve of the receiver, taking the place of the loud speaker in an ordinary broadcast receiver. The illumination from the lamp varies instantaneously with change of anode current, so the brightness varies in accordance with the electrical pulsations produced by the scanning device at the transmitting end. The modulated light from the neon lamp is then made to pass

through the apertures of a second Nipkow disc identical with that at the transmitter. A translucent screen, such as a ground glass screen, is placed close to the disc on the opposite side to the lamp, as indicated by the schematic diagram of Fig. 3. Moving light spots are then thrown on to the screen and when the conditions are correct the picture is reassembled. By interposing a lens between disc and screen an enlarged picture can be obtained.



TELEVISION. Fig. 3. Illustrating method of reception with the Nipkow disc. In practice, lenses are used to improve the optical conditions.

The condition for the formation of a picture is that the eye should see at any instant only that small area of the illuminated screen which corresponds exactly to the particular picture element opposite the aperture in the disc at the transmitter at that instant. (As the velocity of radio waves is about 186,000 miles per second the slight time lag can be neglected at short distances. In any case, it makes no difference to the operation.) In this way all the picture elements are reassembled in their correct positions with their correct relative intensity of illumination, the persistence of vision giving the effect of a complete picture.

The Problem of Synchronizing. It is obvious, then, that the disc at the transmitter must rotate at *exactly* the same speed as and in synchronism with that at the receiver, and this has been one of the problems to be solved, without the use of a special channel between transmitter and receiver for transmitting synchronizing signals. It has been satisfactorily accomplished by superimposing a special rhythmic synchronizing signal on the main signals representing the vision. A black strip is arranged along the top of the transmitted picture, as in Fig. 1, so that a sudden drop and rise of photo-cell current occurs at the beginning of each scanning line. This current pulsation occurs at a definite fixed frequency and can be separated out by suitable filters at the receiver, where the disc is driven by a motor supplied from a local source, its speed being controlled by the synchronizing impulses through the medium of a phonic wheel mounted on the same shaft as the main motor. The phonic wheel exerts a small braking effect when the main motor tends to run too fast, or an accelerating effect when the tendency is to run too slowly. The discs are thus kept at the same speed exactly.

But they will not necessarily be in synchronism, that is, their relative angular positions may not be correct. This results in a divided picture—the right-hand portion might appear on the left, and *vice versa*, with a dividing line between, as in Fig. 4 (left). It is a matter of easy manual adjustment to correct this error by retarding the disc slightly until synchronism is obtained. On the other hand, the picture may be divided horizontally, as in Fig. 4 (right). When this happens the "framing" is said to be out and is corrected by adjusting the angular position of the stationary part of the synchronizer.

Televising Moving Objects. The outline given above indicates the basic principles of scanning, but in practice considerable elaboration of the optical systems and scanning methods are necessary. So far we have only considered the televising of a stationary transparency, but obviously the method could be applied to the successive scanning of the pictures of a cinematograph film, a moving picture being reproduced at the receiver. But in the televising of actual moving objects no transparency is available, and reflected light from the objects within the field must be depended upon. The method of

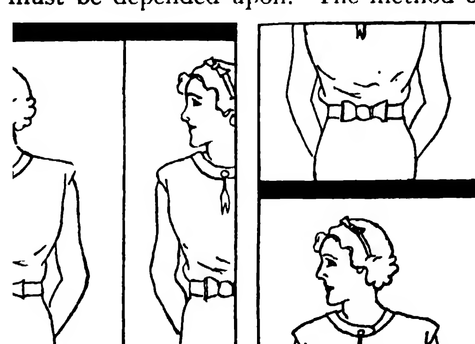
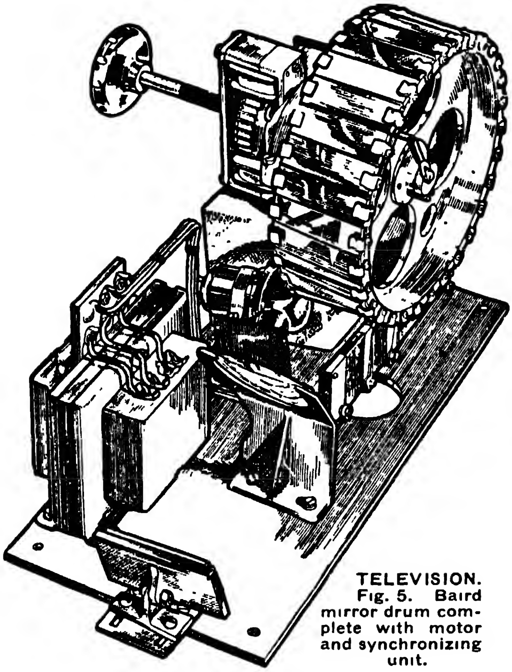


Fig. 4. Possible effects when the receiving disc is not in synchronism with the transmitting disc but when their speeds are equal. With unequal speeds a stationary picture is not obtained.



TELEVISION. Fig. 5. Baird mirror drum complete with motor and synchronizing unit.

Baird Television, Ltd.

illuminating the whole of the subject and forming an image on a screen proved unsatisfactory from the first, owing to the intensity of illumination required; the discomfort to artistes proved too great.

A more successful and practical system employing mechanical scanning is that in which a scanning spot is made to traverse the field. By placing an intense light behind a Nipkow disc a series of extremely bright spots of light are passed across the subject in succession in parallel lines, on the same principle as applied to the scanning of the film. The *reflected* light from the subject is then focussed through a lens on to the photo-cell. With this arrangement the average illumination is comfortable to the sitter and, owing to the speed of scanning, appears to be steady. But actually the whole of the subject, except the small area illuminated by the light spot, is in darkness!

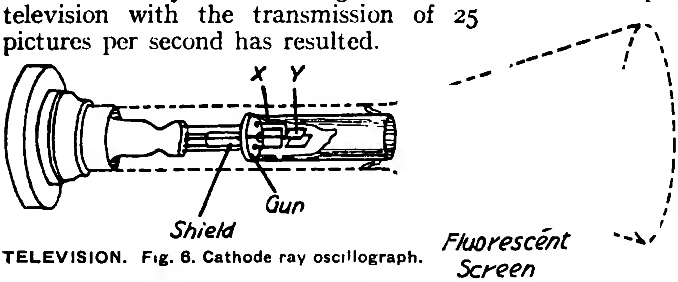
To some extent the Nipkow disc method of scanning has been replaced by a mirror drum method which has proved to possess considerable advantages. A number of plane strips of mirror corresponding to the number of holes in the Nipkow disc are mounted on the periphery of a rotating drum. A beam of light is directed on to the drum and reflected by the successive mirrors on to the subject to be televised, or on to the screen at the receiver, as the case may be. The individual mirrors are tilted at slightly different angles with respect to the drum axis, so that the reflected scanning spots cover adjacent strips of the field in exactly the same way as with the disc.

Factors Governing Definition. The amount of detail possible in the received picture depends primarily on the number of elements into which it is divided, and this is directly proportional to the number of scanning lines per picture. In the very valuable experimental transmissions put over by the B.B.C. in conjunction with Baird Television, Ltd., 30-line scanning was used. The picture was divided into 30 strips, and $12\frac{1}{2}$ complete pictures were transmitted per second, this constituting 375 line-scans per second. For a picture with a length to breadth ratio of 5/4, the scanning lines being in the direction of the larger dimension, the number of picture elements per line would be $\frac{5}{4} \times 30 = 37{\cdot}5$, assuming a square scanning spot. This gives $30 \times 37{\cdot}5 = 1{,}125$ elements per complete picture, or over 14,000 elements per second. Since one cycle of A.C. occurs for each two picture elements, it follows that the electrical frequency involved with a 30-line scan is of the order of 7 kcs., requiring a radio-frequency channel of 14 kcs.; that is, two 7 kc. sidebands.

Even this is higher than can be transmitted over the usual broadcasting wave-lengths without causing or experiencing interference. The cutting off of the higher frequencies reduces the definition somewhat. The degree of definition obtainable with 30-line television is sufficiently good providing the subject itself does not contain too much detail. For instance, the televising of the head and shoulders of a sitter gives fairly satisfactory results, but a group of people at a moderate distance would appear very much blurred. Better definition can only be obtained by increasing the number of scanning lines per picture, and this involves the use of a wider frequency band than normal wave-lengths permit.

Cathode Ray Television

Although the application of the cathode ray oscillograph to television is not new, recent developments and improvements in design have resulted in considerable advancement in this direction. By its use all scanning is performed electrically, there being no moving parts whatever in the apparatus. This means that the number of scanning lines can be greatly increased so that far better definition is possible than with disc or mirror drum methods. Very successful high definition television with the transmission of 25 pictures per second has resulted.



TELEVISION. Fig. 6. Cathode ray oscillograph.

The elements of a cathode ray oscillograph tube are shown in the sectional drawing of Fig. 6. Full details of the action of the cathode ray oscillograph for general purposes are given under the heading Cathode Ray Oscillograph. Its application to television will be perceived from the following outline description.

In operation a narrow beam of electrons issues through the hole in the anode or "gun" and produces a small luminous spot on a fluorescent screen at the end of the glass tube, at the point of impact of the electrons. The beam of electrons can be deflected in two directions mutually at right angles by voltages applied to the respective pairs of deflecting plates, and this effect is utilized for scanning purposes in television.

The cathode ray tube can be used at both transmitting and receiving ends, but as its action in the capacity of receiver lends itself to a somewhat simpler explanation, this will be considered first.

A steadily increasing voltage applied to one pair of deflecting plates moves the spot across the screen, say from top to bottom along the right-hand edge of the picture being formed, giving one vertical scan. At the end of the stroke the spot is almost instantaneously returned to the top of the screen. During this time a small change of voltage occurs between the other pair of deflecting plates, moving the spot to the left by an amount equal to its diameter, so that on its next journey from top to bottom it covers an adjacent strip of the screen, and so on until one complete picture has been scanned. The luminous spot is then returned rapidly to the top right-hand corner, and the next picture is commenced. The course of the spot during one complete scanning of the picture is indicated in Fig. 7, where the full lines represent sweep speeds and the broken lines rapid returns.

Time Base Circuits. For the moment the light modulation will be ignored and the methods of obtaining the requisite deflecting voltages will be considered. To obtain a line scan, the luminous spot must move with constant speed across the screen, and this means that the deflecting voltage between the pair of deflecting plates concerned, which we shall in this article call the Y plates, must rise at a uniform rate, for the deflection of the electron beam is directly proportional to the voltage. In practice it is a very easy matter to obtain a uniformly rising voltage across a condenser by charging the latter with a constant charging current. Over a wide range of anode voltages the anode current of a screen grid valve or a pentode (or even a saturated diode) is practically constant, and this property is utilized to meet the necessary charging conditions.

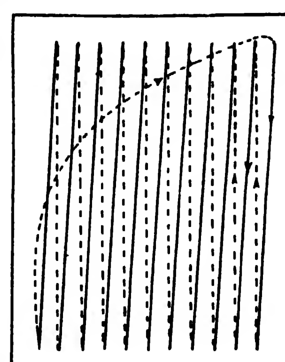
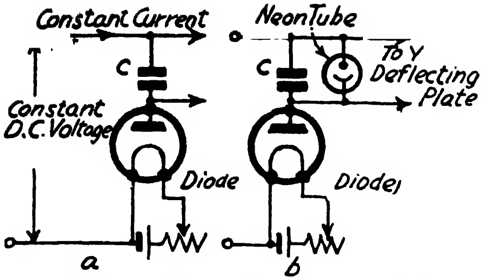


Fig. 7. Cathode ray scanning. The full lines represent the course followed by the light spot.

The simple principles of the device will be readily understood from Fig. 8 (*a*), where a saturated diode is used for maintaining the charging current constant to the condenser C, the rate of charge



TELEVISION. Fig. 8. Simple circuits showing principle of obtaining time-base voltage.

depending in this case on the filament temperature of the diode, and therefore adjustable. Owing to the fact that the current is extremely sensitive to changes in filament temperature a screened pentode is to be preferred in practice, the charging current then being adjusted by the voltage applied to the control grid. The Y plates are connected across the condenser.

The next requirement is that the condenser should be discharged as rapidly as possible as soon as the voltage across its terminals reaches a certain maximum value. This is also easily arranged by connecting a gas discharge tube such as a neon tube or gas-filled triode (called a thyratron) (*q.v.*) directly across the terminals of the condenser, as in Fig. 8 (*b*). Such a device passes no current at all until the voltage reaches a certain critical value at which ionization suddenly occurs, the tube is fired and the condenser is rapidly discharged through it.

The simple neon tube has the disadvantage of a very limited range between striking and extinguishing voltages, about 30 volts only, and as the cathode ray tube requires a voltage sweep of the order of 400 volts, special neon-filled or mercury vapour-filled triodes have been produced for the purpose. With such a valve no discharge will occur until the anode voltage reaches a value *n* times as great as the negative voltage applied to the grid, this factor *n* being called the control ratio. Once the discharge commences, however, it is out of control of the grid and the condenser is rapidly and almost completely discharged. The process is then repeated.

With the neon tube of Fig. 8 (*b*) replaced by such a gas discharge tube the voltage across the condenser rises and falls in the manner shown by Fig. 9, giving a sawtooth diagram, which is what is required for the vertical scanning lines on the screen of the oscillograph. The arrangement causes the light spot to oscillate from top to bottom of the picture, moving upwards at a very much greater speed than downwards.

Now, if the second pair of deflecting plates (X) were maintained at constant potential difference, the light spot actuated by the time-base system just described would move up and down over the same strip of the screen. Therefore, a second time-base voltage must be applied to the X plates, giving horizontal deflection at a comparatively slow rate, to give the effect of Fig. 7. Assuming 30 scanning lines, the horizontal time base in seconds must be exactly 30 times as long as the vertical one. The method of obtaining it is exactly the same, the only difference being one of speed, determined by the condenser value and the constant charging current.

Synchronizing and Interlocking. It follows that the two time bases must be interlocked so that the frequency of one is exactly 30 times that of the other. This can be done by transferring a fraction of the voltage from the high-frequency or vertical time-base system to the grid of the gas discharge tube controlling the other, a small variable condenser being connected from the anode of the H.F. tube to the grid of the L.F. one. During the last vertical stroke of the spot downwards on the left, the time-base voltage of the horizontal control is nearing the value at which the discharge tube strikes and the small impulse applied to the grid from the vertical system ensures that the tube shall be flashed at exactly the right instant, returning the spot from the bottom left to the top right-hand corner, when the process of scanning is repeated.

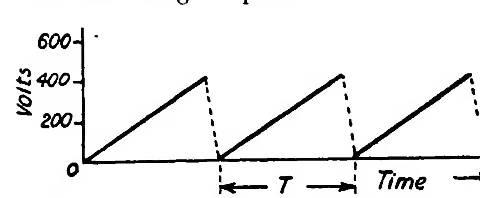
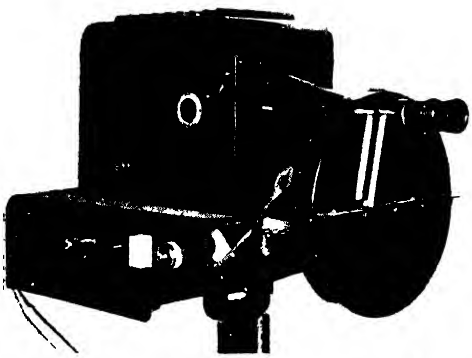


Fig. 9. Saw-tooth time-base voltage obtained from screened pentode—gas discharge tube combination. For 120-line 25 picture scanning the periodic time $T = \frac{1}{3{,}000}$ sec.

Synchronizing the receiver tube with the transmitter is effected on the same principle. A synchronizing signal is radiated from the transmitter at the end of each line scan as explained for the disc method, and this impulse is applied, at the receiver, to the grid of the higher frequency time base tube, so that each line scan commences at exactly the right instant. It should be realized that the cathode-ray type of receiver operates satisfactorily on disc transmitted television.



TELEVISION. Fig. 10. Scanning head of Marconi 60-line television transmitter using Nipkow disc.

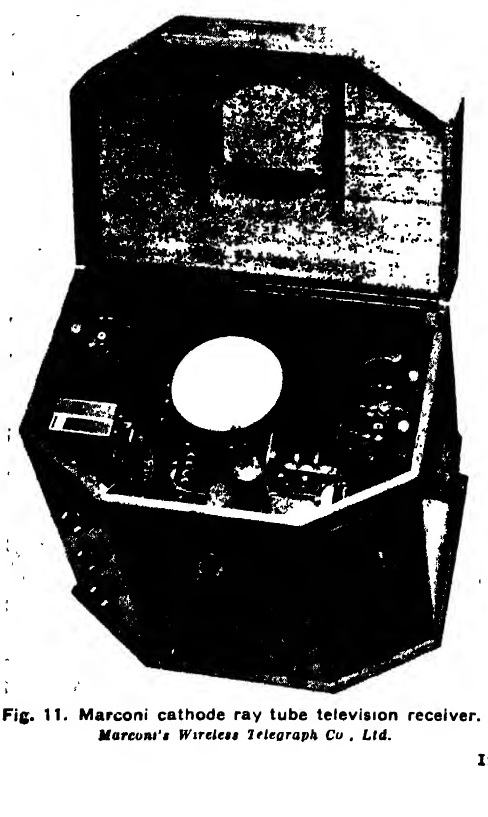


Fig. 11. Marconi cathode ray tube television receiver.
Marconi's Wireless Telegraph Co., Ltd.

The Cathode Ray Transmitter. As the cathode ray receiver can be made to deal with H.D. scanning quite satisfactorily, it follows that in such a system cathode-ray methods can be used at the transmitter also. The scanning arrangements at the transmitter are exactly the same as described for the receiver, but considerable difficulty is experienced on the optical side. This is because the oscillograph itself has to provide the illumination, and at first it was only possible to use cinematograph film subject matter for transmission by this means, but direct transmission later became possible with special electron camera systems outlined below.

The scanning spot on the screen of the cathode ray tube is focussed on to the film, through which it passes, in varying degrees of intensity, into the photo-cell. One of the difficulties has been the persistence of the fluorescence on the screen for a fraction of a second after the electron bombardment has ceased.

Light Modulation. In the ordinary way the intensity of the luminous spot can be varied by altering the voltage on the cylindrical shield surrounding the cathode, a change of 20 or 30 volts being sufficient to control the light intensity between full brilliance and darkness. By applying the received signal voltages to this shield the necessary light modulation is obtained.

There is, however, a disadvantage that the focussing of the electron beam is upset to some extent by this method, causing the scanning lines to widen and run into each other, when an attempt is made to use fine scanning. In the system developed at the Cossor valve works, and described by Bedford and Puckle in a paper read before the Wireless Section of the I.E.E., this drawback has been overcome by an ingenious method. Instead of varying the intensity of the luminous spot on the screen, velocity modulation is employed. A light spot travelling at high speed produces a fainter apparent illumination than at low speed. Over the lighter parts of the picture the luminous spot (of constant intensity) moves relatively slowly, and rapidly over the dark parts. The effect is very easily accomplished at the receiver by superimposing the signal voltages on the line-scanning time-base voltage so that the spot moves from top to bottom

with variable velocity according to the gradation in the strip of the picture covered, but the total time taken to cover one complete line scan is unaffected.

Considerable complication is introduced at the transmitter, where the output from the photo-cell is made to react back on to the scanning oscillograph in such a way as to vary the velocity of the spot according to the gradation of the cinema film. Intensity modulation combined with velocity modulation has been used to give better contrasts.

High-Definition Television. The greater the number of scanning lines the better is the definition of the picture, within practical limits. The year 1936 marked the inauguration of a high-definition service from the Alexandra Palace, two systems being adopted, namely, the Baird and the Marconi E.M.I. systems. The former employs 240-line horizontal scanning of a 4×3 horizontal picture—25 pictures per second. The latter employs 405-line interlaced scanning.

The signal frequencies involved in H.D. television are very high indeed. The maximum frequency to be dealt with is given by the expression:

$$\text{Frequency} = \frac{(\text{Scanning lines})^2 \times (\text{picture ratio}) \times (\text{pictures per sec.})}{2}$$

Thus with 240-line scanning and 25 pictures per second, picture ratio $\frac{4}{3}$, the frequency is 960,000 cycles or 960 kc. per sec. Allowing 10 per cent. for the time required for synchronizing impulses, the actual maximum frequency is 10 per cent. greater, namely, 1,056 kc.

Why Ultra-Short Waves are Necessary. With 240-line television we require a modulation frequency of over 1,000 kc. and therefore a total channel width of over 2,000 kc. Now a 300-metre wavelength constitutes a carrier frequency of only 1,000 kc. and so it is technically impossible to use medium and long wavelengths for H.D. television. The medium-wave band from 200 to 600 metres embraces 1,000 kc. (about 110 channels of 9 kc. each), and a single H.D. television transmission requires twice this band width. The frequency separation of two ultra-short wavelengths of 3 and 10 metres is 70,000 kc., sufficient to accommodate 35 transmissions, each with a 2,000 kc. spread. The suitability of ultra-short wavelengths for H.D. television is thus evident. In the H.D. television from the Alexandra Palace the carrier wavelength for vision is 6·6 metres and for associated sound 7·2 metres. Although the wavelength separation is only 0·6 metre the frequency difference is 3,800 kc.

Electron Scanning Systems. Owing to the limited amount of light obtainable from the screen of a cathode-ray tube this device in its usual form is not suited to H.D. scanning at the transmitter. There are, however, other systems employing scanning by electron beams or the equivalent, and possessing considerable advantages over mechanical methods. High-speed scanning is easily effected, and outdoor scenes may be televised. The two systems of electron scanning developed in this country by Baird and Marconi E.M.I. respectively are outlined below.

The Farnsworth Electron Image Camera. Farnsworth in America produced two devices, namely, the "Image Dissector" and the "Electron Multiplier," which are combined to form a single unit called an "electron image camera." The scanning is done by the image dissector and the amplification of the picture signals by the electron multiplier.

The image dissector consists essentially of a flat cathode and a flat anode situated at the two ends of an evacuated glass tube, their faces being parallel as shown in Fig. 12(*a*). The cathode consists of an extremely thin film of silver on the end of the tube itself. The coating of silver is so thin as to be translucent and is coated on the inside with a film of caesium oxide which emits electrons under the action of light. The anode at the other end of the tube has a small hole through the centre.

The scene or object to be televised is focussed by an ordinary photographic lens on to the cathode end of the tube, the light passing through the translucent silver film and reaching the caesium. The number of electrons emitted from any small area of the caesium film is directly proportional to the amount of light reaching that part and therefore to the brightness of the image there. The freed electrons are then attracted towards the positive anode. Now, in the ordinary way, the electrons would be emitted from the

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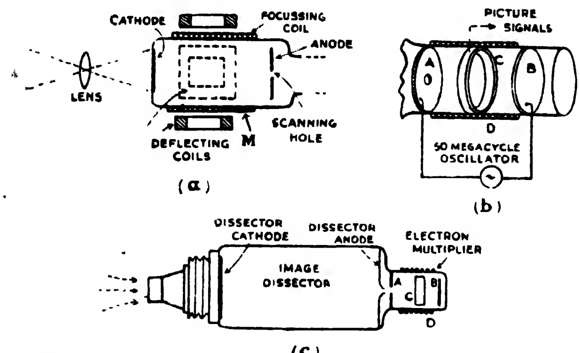
cathode in various directions and on reaching the anode would be more or less evenly distributed. But by means of a magnetizing coil M, surrounding the tube, a focussing of the electrons is obtained and



TELEVISION. Fig. 12. (a) The image dissector. (b) The electron multiplier. (c) Electron image camera arrangement combining (a) and (b).

an "electron image" (invisible) is produced on the anode.

Scanning is effected by moving the *whole image* in horizontal and vertical directions across the scanning hole in the anode by the magnetic fields of two pairs of deflecting coils on opposite sides of the tube. The electrons passing through the anode hole constitute the picture signals.

The Electron Multiplier. With actual scenes the picture signals given by the image dissector are too weak and the electron multiplier augments the number of electrons coming through the hole from each part of the image as it is scanned. The arrangement is as shown in Fig. 12(*b*). A and B are two caesium-coated parallel electrodes, and C is a collector ring anode in an evacuated tube. The electrons shot through the hole in A are projected on to B, being prevented from reaching C by a strong axial magnetic field due to a magnetizing coil D. Each electron striking B liberates five or six secondary electrons which are attracted towards the ring anode C, but pass through due to the magnetic field and strike A, liberating further secondary electrons. To maintain the to and fro motion of electrons in this way, the P.D. between A and B is made rapidly alternating at 50 megacycles per sec. by means of an oscillator. To prevent eventual saturation an additional interrupting frequency is applied to stop the action at very short intervals, allowing the anode C to collect all the freed electrons, which constitute the amplified picture signal which is passed on to the radio transmitter.

Fig. 12(*c*) shows the complete camera arrangement comprising the combined image dissector and electron multiplier. It is compact and portable and may be used for both indoor and outdoor work.

The Iconoscope. This is also of American origin, being due to Zworykin. The device consists of a modified form of cathode-ray tube in which the fluorescent screen is replaced by a special kind of screen electrode on to which an image of the scene to be televised is focussed by a photographic lens. The arrangement is shown in Fig. 13, where M is the screen electrode. This consists of a thin mica sheet with a metal plate as backing. By a special process minute silver globules are formed on the front of the mica and oxidized so that they are insulated from each other. They are then coated with caesium. The "mosaic" so formed is then sensitive to light, each globule being in effect a tiny photo-electric cell, and at the same time, in conjunction with the back plate, a small condenser.

When an optical image is formed on the mosaic the globules throw off electrons to an extent depending on the intensity of the light, and the "condensers" become charged to corresponding degrees in accordance with the light and shade of the picture. The screen is now scanned in strips in the ordinary way by the electron beam, as already explained, by applying saw-tooth voltages to the deflecting plates of the tube.

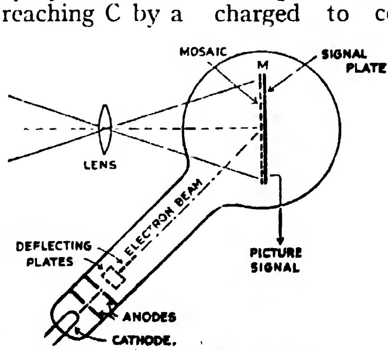


Fig. 13. The Iconoscope system.

Those globules on which the beam impinges have electrons

imparted to them and, as condensers, are discharged. The charging and discharging currents appear at the back plate and constitute the picture signals. Consequently during the scanning the current obtained varies in accordance with the brightness of the part of the image passed over by the scanning beam.

In high-definition work the necessary saw-tooth voltage for line scanning is obtained from special hard valve circuits, as gas-filled discharge valves have an inherent time lag.

TEMPERATURE COEFFICIENT. The resistivity of a metal almost invariably rises with an increase of temperature, and hence where great accuracy is required it is very important to know the temperature at which a conductor will have to work.

Between the limits of temperature which commonly occur, the change of resistance is strictly proportional to the temperature change. The actual increase is also proportional to the original resistance, and for a given change of temperature the change of resistance of a conductor may be expressed as a percentage of the resistance at the lower temperature. It thus becomes convenient when comparing this property for different metals to reduce it to one common basis, that chosen being the percentage increase for 1° C. rise of temperature. This quantity is called the temperature coefficient of resistance for the material, so that if the temperature coefficient of copper is said to be 0·388, it means that a copper conductor of 100 ohms resistance at 0° C. will, when warmed to 1° C., have a resistance of 100·388 ohms.

It is clear that the increase of resistance is not due to the expansion of the metal producing a change in the dimensions merely, since any increase in length due to heating is accompanied by an increase in cross-sectional area. In fact, the increase in area due to expansion occurs at a greater rate than the increase in length, and on this basis the resistance should decrease. The change in resistance is a physical property apparently quite independent of the coefficient of expansion.

The temperature coefficient does not always increase at the same rate in certain alloys, some metals having a rising resistance-temperature curve in the early stages, and a drooping one at a later stage. A limited number again possess drooping characteristics from the very outset, and these latter are classed as "negative" temperature coefficients. A complete list of the temperature coefficients of the various metals and alloys will be found under Resistance (*q.v.*).

TEMPERATURE EFFECTS: In Instruments. Most electrical measuring instruments are affected to some degree by temperature, and the aim of a good design is to minimize temperature errors as much as possible.

In moving-coil instruments a high swamping resistance (*q.v.*) is used, and the resistance of the moving coil is then very small compared to the total resistance between terminals, so that, by this device, temperature changes are extremely small in well-designed instruments. In shunted instruments the temperature error is liable to be greater on account of the necessity of getting sufficient copper wire on the moving coil to give the desired maximum torque, and a compromise between torque and accuracy must be made. In moving-iron instruments high value swamping resistances cannot be used so that temperature changes affect such instruments more than in the case of moving-coil instruments.

In dynamometer type instruments required for measuring the larger currents, it is usual to employ shunts, the temperature coefficient of resistance of which may be different from that of the instrument windings. Temperature changes then alter the ratio of shunt to winding resistances and instrument accuracy thereby becomes affected.

In hot wire instruments, the plate carrying the working components should have the same coefficient of expansion as that of the hot wire.

Induction instruments are liable to temperature errors due to variations in resistance of the rotary disc and of series and shunt windings. The temperature coefficient of an induction meter varies with the power factor, and temperature changes may be responsible for appreciable inaccuracies at higher power factors. Temperature increases generally tend to under-registration and *vice versa*.

TEMPERATURE RISE. The principal factor limiting the output which can be

obtained from a dynamo or motor is the heating effect produced in the armature, commutator and field windings. A limit is set to the permissible temperature rise in a dynamo or motor by the fact that the materials which are used to insulate the copper conductors in the slots and other parts are necessarily materials which cannot stand a high temperature, such as the cotton covering, tape or cotton braiding on the armature and field windings, and the paper or insulating cloth, etc., which is used to insulate the winding from the armature core.

The mechanical construction of the machine also requires that the heating should not be excessive, otherwise injurious strains due to metallic expansion and contraction may be set up. Further, the pressure regulation of the machine may suffer if the temperature attained is excessive, owing to the increase in electrical resistance of copper with temperature.

Modern practice demands that the temperature rise under stated running conditions should not exceed about 45°–55° C., and this means that under a severe overload the temperature rise may be as much as 70° C. above the surrounding atmosphere. The heating of the armature is, of course, the result of the losses taking place in the windings, and the iron or core losses. It is an easy matter to calculate the watts lost in the copper, knowing the resistance of the armature conductors and the current flowing through them. Similarly, knowing the thickness, quality and weight of the laminations composing the core, the density of the magnetic flux and the frequency, we can calculate the iron loss in watts. The actual losses in the core vary considerably according to the method of building up in the shops and considerable margin must be allowed in the heating calculation for a possible increase in loss over that anticipated.

The temperature rise depends upon the total number of watts lost in the copper and iron in relation to the exposed surface and the general fanning action, and it is obviously desirable to make the armature as well ventilated as possible in order to utilize to the maximum a given weight of copper and iron.

Thus we have all the electrical losses, bearing friction and windage losses, appearing as heat, in the relation that each kilowatt-hour so lost represents 3,415 British thermal units per hour. All this heat has to be removed at the same rate as it appears if the temperature is to remain constant. It is conducted from the iron and copper through the insulation to the surfaces, where it is radiated into the air, particularly to the air passed through the machine by means of its fans, warming this air by a definite amount. The actual temperature attained by any part of a machine depends upon the emissivity of its surface, which in turn depends upon its character (chiefly texture) and colour, the initial temperature of the air in contact with it, and the velocity of the air. Thus the design of an electrical machine, from the temperature rise point of view, is a very complicated matter, involving the knowledge of the physical characteristics of many materials as well as more than the elements of fan design.

Cooling Measures. If the amount of ventilating air becomes reduced the temperature of a machine inevitably rises; hence it is important to ensure that fan blades are kept clear and free from erosion, and that all ventilating ducts are periodically cleaned. This latter is the main reason for the periodical blowing out with compressed air which should be a regular feature of maintenance work.

In oil-immersed electrical gear, such as transformers, the heat of the losses is conducted by the oil to the casing or radiator tubes, the surface of which has an emissivity that is accurately known. It is important, in this case, to ensure that an adequate natural current of air has access to the radiator tubes, for which reason many transformer cubicles are arranged with louvred air inlets, and exits in the form of natural chimneys. In very large transformers, such as those on the "Grid," it is often arranged to increase the velocity of the air upon the radiator tubes by means of fans, so enabling more heat to be taken away and the transformer to carry considerably more load without an excessive temperature rise.

Temperature Rise Measurement. The average temperature rise of the copper

LIMITS OF TEMPERATURE RISE PERMISSIBLE

Item No.	Part of machine	Temperature Rise (measured by thermometer)	
		Machines not Totally Enclosed	Totally Enclosed Machines
1	Windings insulated with Class A materials and cores with which they are in contact.	40° C.	50° C.
2	Commutators.	45° C.	55° C.
3	Slip-rings when not enclosed.	45° C.	55° C.
	Enclosed.	55° C.	55° C.
4	Uninsulated parts including cores not in contact with insulated windings.	The temperature rise shall in no case reach such a value that there is risk of injury to any insulating materials on adjacent parts.	

conductors of a machine or transformer can be ascertained from the increase in resistance of the windings, and this method is recognized by the British Standards Institution. Very accurate measurements of the resistance are necessary if the deduced temperature is to be at all reliable, and the resistance cold must be taken when the machine has really attained the temperature allocated to it. Moreover, in the case of rotor windings, the brush resistance must be eliminated from the voltmeter readings if the fall of potential method of measuring the resistance is employed; this can be done by the use of separate brushes or contacts for the voltmeter leads. Assuming that all these precautions are borne in mind, and the resistance of copper being directly proportional to absolute temperature, we have

$$T = [(t + 234{\cdot}5)\, R \div r] - 234{\cdot}5$$

where T is the final temperature of the hot windings in degrees centigrade, t is the initial temperature of the cold windings in °C, R is the final hot resistance in ohms, and r is the initial cold resistance in ohms. If the temperatures are in degrees Fahrenheit the figure 491 should be substituted for 234·5 in both cases.

In testing whether a motor will, in fact, come within its specified temperature rise on a given duty-cycle, it is not necessary to put it through a complete cycle, but the final temperature may be calculated from the measured temperatures before and after the first part of a repeating cycle. This method saves time on the testing bench but involves very accurate methods of measuring the temperatures.

These points are further discussed in Alternator; Generator; Motor; *see* also Continuous Rating; Intermittent Rating; Rotor; Ventilation.

TEMPERATURE SWITCH. *See* Thermostat.

TENSION: EXTRA HIGH, HIGH AND LOW. *See* Extra High Tension; High Tension; Low Tension.

TERMINAL. Name given to a metallic conductor to which, or from which, electrical connexion may be made. Owing to the extremely varied applications of the terminal and the different classes of work to which it is put, terminals vary alike in size, shape and purpose. As a general rule, terminals are made from brass owing to its relatively slow oxidation and freedom from corrosion.

In accumulators terminals are coated with vaseline to prevent corrosion by the acid, and for the same reason are frequently lead-plated. Terminals are often nickel-plated or lacquered to preserve their appearance and prevent corrosion.

TERMINAL BOX. Term generally employed for any box attached to a machine or apparatus and housing the input or output terminals.

More specifically applied to the outlet box by which switches and other interior fittings can make connexion with concealed wiring buried in plaster or behind wainscoting.

Also used for the box to which a lead-sheathed or wire-armoured cable may be led in and its cores separated to their respective terminals. *See also* Dividing Box; Joint Box, *etc.*

TERRESTRIAL MAGNETISM. An ordinary compass needle, if placed in the neighbourhood of a magnetic field,

will set itself along the lines of force, since in this position the turning moment, or torque, acting upon it becomes zero. Therefore, the fact that a compass needle placed almost anywhere on the surface of the earth takes up a definite position may be accepted as an indication that it is in a magnetic field, the position it takes up being the one in which it lies most nearly in the direction of the lines of force of that field. The field so pointed out is that due to the earth, which, as Gilbert asserted, behaves as a large magnet. The direction taken up by the compass needle is approximately, but not accurately, north and south; the direction actually indicated is known as that of the magnetic meridian, at the place, and the angle between this and the true geographical meridian is known as the declination or variation of the needle. The declination has widely different values at different points on the earth's surface, and the fact that the two meridians are not identical shows that the magnetic and geographical poles do not coincide.

Besides the form of needle termed the declination needle, there is another termed the inclination, or dipping, needle. The angle made by the direction of the needle and the horizontal plane is called the inclination, or angle of dip. It has been ascertained that the inclination or dip also varies from place to place. The maximum inclination occurs at the magnetic poles, where the needle is vertical, and at about half-way between these poles the angle of inclination is zero, the needle lying horizontally.

A complete knowledge of the earth's magnetic field at any place is usually obtained by three distinct measurements by which what are known as the magnetic elements of the place are determined. These magnetic elements are:

The declination or variation; the inclination or dip; the horizontal component of the magnetic force, usually called the horizontal force.

Such measurements have been made at various points on the earth's surface, and the results embodied in charts. The chart for the variation is an extremely important one for mariners, as without making due allowance for the variation navigation on long ocean voyages could not be carried on. Fairly good measurements of the magnetic elements may be made with comparatively simple apparatus, but for their determination with high accuracy more elaborate arrangements are necessary.

TERTIARY WINDING. An auxiliary winding sometimes incorporated in transformers for such purposes as stabilizing the neutral potential, preventing harmonics, etc. *See also* Static Frequency Changer; Transformer.

TESTS AND TESTING: INSULATION, JOINT AND MAGNETIC

By C. L. Lipman, A.M.I.E.E.

This section covers the whole ground of testing in electrical work and deals with insulation, joint and magnetic testing, in particular. It should be read in conjunction with Faults and Fault Location in Motors and Cables, and with the article that follows on Testing Sets and Testing Instruments. See also under the names of individual tests as Flash Test; Blavier's Test; Hopkinson Test; Insulation; Loop Test; Short Circuit; and Varley's Loop Test.

All classes of electrical work are subjected to tests of some kind or another. They embrace the raw or composition materials to ascertain their electric or magnetic properties, and the finished apparatus, machines, cables, or complete installations, to determine their performance, efficiency and general compliance with the various clauses of the appropriately prescribed specifications.

The reasons for testing are many and varied, but the following are of practical significance:

(*A*) *Prevention of Breakdowns.* Breakdowns mean loss of output and inconvenience, and may cause damage to apparatus and injury to individuals.

(*B*) *Detection and Location of Faults.* A fault should be detected in its incipient stage and its position located with minimum delay and by simple and economic means.

(*C*) *To effect Savings in Power Bills.* Much plant operating expenses can be often saved by simple testing to determine whether motors are properly loaded, loads balanced, and, in the case of A.C., the power factor conditions of a given circuit.

Testing to be effective must be carried out in a systematic manner in accordance with established proved methods for each class of work, and by the use of measuring and testing instruments specially designed for the purpose.

Commercial testing of D.C. circuits is comparatively simple, and is mainly concerned with the measurement of current in ampères, pressure in volts, power in watts, energy in kW-hours (or Board of Trade Units) and resistance in ohms. Whereas the testing of A.C. circuits involves, in addition to the above, the measurement of power factor, inductance, capacity, impedance, reactive power, apparent power, frequency and wave form.

The majority of the electrical quantities mentioned above can be measured by means of direct reading deflectional type instruments in which the pointer moves over a graduated scale, the instrument being previously calibrated in the required units; for example, those described under the headings Ammeter, Voltmeter, Wattmeter, Frequency Meter, etc. Other quantities are determined by the " zero " method, *i.e.* by means of Bridges (*q.v.*) or Potentiometers (*q.v.*), where the unknown is balanced against a known quantity of the same kind or the equivalent. The latter method is universal in its application and is capable of precision accuracy, if due care and precautions are taken.

Of the testing processes commonly employed, the insulation, joint and magnetic testing are of considerable practical importance, and these will now be considered under their respective headings.

Insulation Testing

All electrical apparatus and plant have to be tested for insulation and dielectric strength, *i.e.* resistance to breakdown by high voltage.

House and industrial wiring installations are subjected to insulation resistance tests only. The latter tests are carried out with an insulation testing set, *e.g.* a Megger, in the manner illustrated and described in Fig. 1, page 810. It will be noted that in order to test an installation thoroughly it is necessary to apply a test between conductors, as well as between each conductor and earth.

The insulation resistance is measured quantitatively by the application of a D.C. voltage of the order of 500 volts for a period sufficiently long for the needle of the testing instrument used to become steady. The method of testing the insulation resistance of a D.C. motor is illustrated in Fig. 2, page 810.

The insulation resistance of industrial and mining wiring installations and machinery should be tested at regular intervals, and the results, and comments relating thereto, recorded in a suitably arranged log-book. A useful entry is the state of weather, as this may affect the readings of insulation resistance obtained.

H.V. Tests. The " high voltage " or " flash " test to earth, which is designed to determine the factor of safety of the insulation, is carried out with an alternating voltage, usually at 50 cycles per second, and for the period of one minute. The value of the test voltage depends on the working or " rated " voltage of the system, on the type and nature of the apparatus to be tested, etc. Suitable values are given in the corresponding B.S.I. Specifications (*see* page 521), and these should be consulted, in each individual case, before making the tests.

The wave form of the test voltage curve should be as nearly sinusoidal as possible. For a pure sine wave voltage the crest value is 1·41 times the R.M.S. value, and care should be exercised not to exceed this to any great extent. For most machines the R.M.S. value of the test voltage is

1,000 PLUS TWICE RATED VOLTAGE

with a minimum of 2,000 volts.

Certain apparatus, *e.g.* transformers, should be subjected to higher test voltages than the above, namely

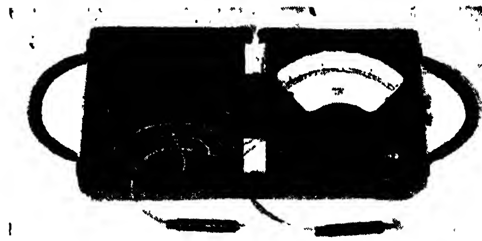
2,000 PLUS 2¼ TIMES RATED VOLTAGE

in accordance with the relevant B.S.I. Specifications.

The high voltage test is commenced at about one-third of the test voltage, and the voltage is then increased as rapidly as possible, the rate of increase depending on the ability of the measuring instrument to indicate the voltage. The full test voltage

is then maintained for one minute, after which the voltage is rapidly diminished to one-third of the full value and then switched off.

In the case of voltage transformers, the insulation between turns is also tested by means of an " induced " high voltage test, usually with twice the rated voltage at twice the rated frequency.



TEST AND TESTING. Fig. 1. Set for earthing continuity tests.
Salford Electrical Instruments, Ltd

JOINT TESTING

The quality or condition of a joint between two or more conductors is judged by the resistance it offers to the flow of an electric current. For the purpose of this section, the term " joint " includes also the bonding of rails and conduits, earth plate contact with the soil, and the contacts of circuit breakers and contactors when they are closed. A defective joint is thus characterized on the one hand by a high volt drop, and on the other hand by a high power loss resulting in excessive heating. The latter may be transmitted to adjacent parts of the apparatus or structure, and so cause temperature rises which may fall outside the safe working limits.

This point emphasizes the importance that should be attached, for example, to the use of joint boxes in the mains of a town distributing system, which, while being economical in space, permit of the jointing of the conductors in such a manner that a thoroughly good electrical conductivity will be obtained between the fittings and the cable conductors.

Joint testing is therefore primarily concerned with the measurement of low resistances. The simplest practical method of measurement for small and medium resistances consists in measuring the voltage drop when a known current is passing through the joint in question. This requires an ordinary direct current ammeter-voltmeter testing set together with a D.C. source of supply.

A convenient portable testing set for this purpose consists of one sensitive moving-coil instrument, capable of being used either as an ammeter or a millivoltmeter or voltmeter (Fig. 1), and provided with a number of standard shunts and series resistances. Fig. 2 shows the instrument connected up so as to measure the low resistance of a joint, J. A suitable current is passed through J,

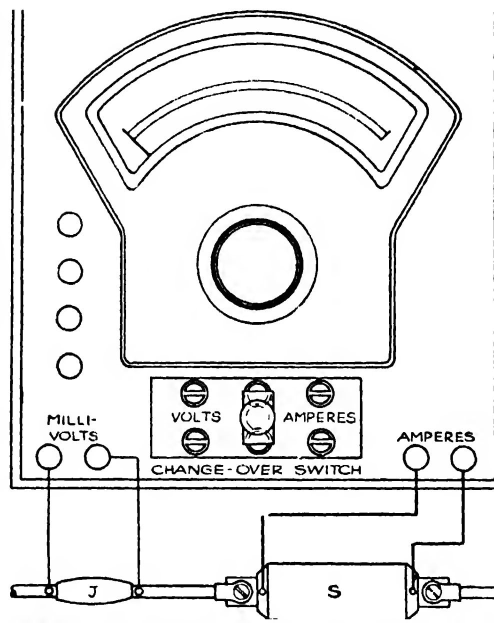


Fig. 2. Connexions of instrument for measuring low resistance of a joint J. S is shunt.

and also through the shunt S, which latter is connected to the moving coil so as to measure the current when the change-over switch on the instrument is in the " ampères " position. Immediately afterwards the switch is turned to " volts " so as to read the voltage drop across J, and, provided there has been no change meanwhile in the value of the series current, the resistance of joint J is calculated from the ratio $\frac{V}{A}$ where V is the reading with switch to " volts," and A is the reading with switch to " ampères." This method of testing is known as the " Fall of Potential " method.

The joint resistance can also be measured by a direct reading instrument, *e.g.* the

'Ducter" low resistance testing set, having five ranges and covering resistances from 5 ohms down to 1 microhm. Low and medium resistances are also determined by the "nul" or "Zero" method of testing the apparatus working on the Wheatstone bridge principle (*see also* Ohmmeter).

Track Bond Tests. For traction work a rail bond testing set is employed. This comprises a contact arm, usually 5 ft. long, which is furnished with two fixed contacts, one at either end, and a third contact about 1 ft. from one end, and the instrument, with all the apparatus necessary for making complete tests, including a moving-coil type galvanometer. The contact arm is placed on the rail so that the bond is between the two contacts spaced one foot apart, a length of solid rail being between the middle and other outer contact.

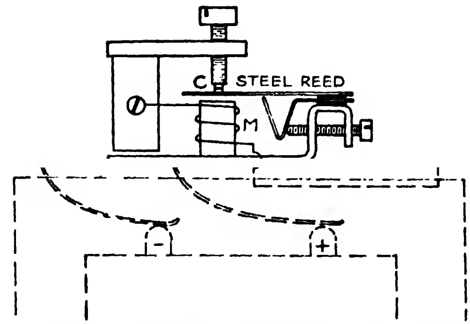
Three leads are brought from these contacts to the instrument. By means of the milled head on the instrument the index is moved over a scale graduated in terms of length of solid rail. The bond resistance is thus read off direct as being equivalent to so many feet of solid rail. If desired, the actual resistance of the bond in ohms can readily be determined.

If no track current is available, testing current from a few storage cells can be injected into the rail.

In wiring installations where metallic sheathing or conduit is used, it must be electrically and mechanically continuous and connected to earth. The value of 1 ohm is that given by I.E.E. Regulations for the maximum resistance of an earth connexion between any two points.

The "earth plate" resistance to earth is measured by an "earth plate" testing set employing auxiliary electrodes, *e.g.* Megger earth tester. The latter gives readings of the resistance to earth directly in ohms, the readings not being affected by soil electrolysis or vagabond currents. The resistance to earth should be initially low and successive periodic tests should continue to give low readings.

Continuity Tests. In everyday commercial practice a large proportion of joint testing is concerned with the proof of "continuity" of an electric circuit. The majority of continuity tests are of a



TEST AND TESTING. Fig. 3. Buzzer type detector for continuity testing. M is electro-magnet, a steel reed, C contacts.

qualitative, and not quantitative, character. This feature permits even simpler and less expensive testing apparatus being employed; often a simple buzzer (*q.v.*) or telephone detector is sufficient. In view of their great practical value to manufacturers and contractors, continuity and open circuit tests require detailed consideration.

A very simple arrangement of a buzzer type detector is illustrated in Fig. 3. It consists of a small electro-magnet, M, a steel reed, and a pair of contacts C, of which one is fixed to the frame and the other free to vibrate with the reed. This mechanism is mounted on the top of a small portable case containing a 4-volt dry battery and a pair of terminals, to which the circuit to be tested is connected. A common application is illustrated in Fig. 4. The circuit to be tested is assumed to contain the winding of an ammeter, the current coil of a wattmeter, an overload relay and a resistance, representing say a length of leads, there being at least six joints in all, soldered or otherwise. The buzzer is connected to the two ends of the circuit as shown.

If the joints are satisfactorily made a current will flow through the circuit, and

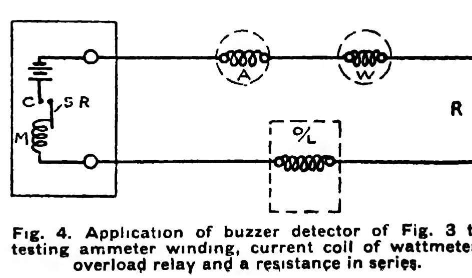
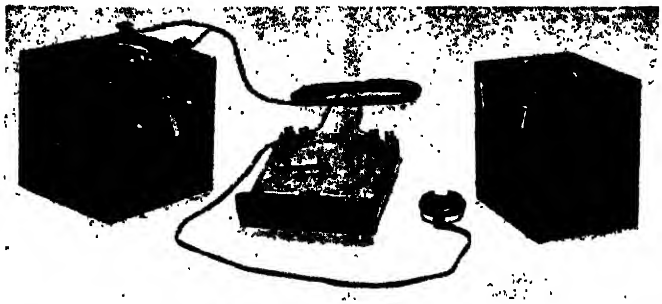


Fig. 4. Application of buzzer detector of Fig. 3 to testing ammeter winding, current coil of wattmeter, overload relay and a resistance in series.



TEST AND TESTING. Fig. 5. Apparatus in the form of direct reading Wheatstone Bridge, specially designed for testing lightning conductors. No special skill or calculation is necessary, the results being clearly indicated on the dial.
Elliott Bros. (London), Ltd.

therefore through the coil of the electro-magnet M, and the reed will vibrate, emitting thereby a peculiar note. Silence of the buzzer obviously indicates an open circuit. The device is also sensitive to changes in the circuit conditions. If, for example, the resistance R is shorted out a higher current will flow through the coil M and the pitch of the note emitted by the reed will change accordingly.

Another useful circuit detector consists of a portable milliammeter in series with a high limiting resistance (usually provided with tappings) and self-contained with a 4-volt dry battery and a pair of leads. A defective or intermittent joint in a circuit is detected by the unsteadiness of the deflection of the needle of the measuring instrument. The circuit tester is usually provided with a double scale, a current scale in milliampères and a resistance scale in ohms.

Magnetic Testing

Industrial magnetic testing is chiefly concerned with the determination of the magnetic properties of ferro-magnetic materials. A knowledge of the magnetic induction, flux density, permeability and hysteresis loop of a given magnetic substance is of considerable practical importance. Most magnetic measuring instruments are designed with a view to testing comparatively small specimens only. The latter take various forms and dimensions according to the apparatus employed.

A common method of measuring magnetic induction is by means of a ballistic galvanometer (*see* Ballistic Method).

The magnetic strength obtained by the specimen can also be determined, though roughly, from the tractive force which it exerts. The traction permeameter or magnetic balance measures the pull required to separate two magnetized surfaces originally in contact, and this is equated to

$\frac{B^2A}{8\pi}$ dynes, where B is the flux density and A is the cross-sectional area of the magnet specimen in sq. cms.

The flux can thus be readily estimated.

A direct reading fluxmeter (*q.v.*), due to Grassot, can be used as an alternative to the ballistic method in any of the ballistic induction tests. The instrument, which is of the moving-coil type, is used in conjunction with a search coil, made flat for difficult situations, the underlying principle being that the instrument needle deflects until the energy received ballistically has all been absorbed by the electro-magnetic damping of the movement. The reading is independent of the

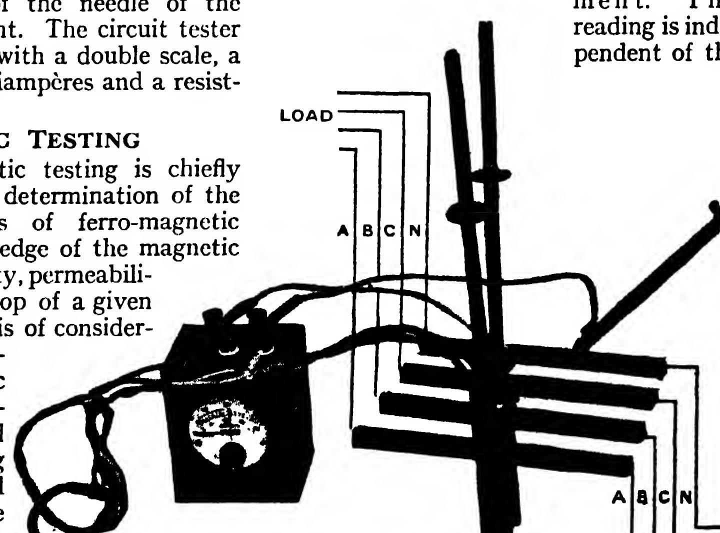


Fig. 6. Elliott direction-finder apparatus (Shotter patent) for ascertaining direction of current flow, designed for use with the Elliott link pattern current transformer, as shown, which measures the current passing through the links in distribution boxes.
Elliott Bros. (London), Ltd.

resistance of the coil circuit, for the quantity and the damping control increase or decrease in the same proportion.

The permeability, denoted by μ, is measured by means of a permeability bridge (*see* Permeameter *and* Permeability Bridge).

The permeability curve is obtained by plotting the permeability against the magnetizing force (H) applied to the specimen or against the flux density (B). The ballistic galvanometer and the hysteresis tester enable the hysteresis characteristics to be obtained. *See further under* Hysteresis Tests.

The various magnetic quantities may also be determined by means of a deflectional type magnetometer. The magnetic strength of the specimen is estimated from the magnetic field which it produces at some point, a magnetic compass needle being placed at this point so as to be deflected by the field produced.

Workshop Flux Tests. Another category of magnetic testing is concerned with the workshop determination of the total flux or field strength and the polarity of permanent magnets as used in the manufacture of electrical measuring instruments. In order, for example, that a given type or class of moving-coil permanent magnet measuring instrument manufactured in large quantities may give the same performance in each individual case it is essential, amongst other conditions, that the permanent magnet, usually of U shape, employed therein should give a field strength which is as near the average value as is practically possible.

The simplest form of workshop fluxmeter for this purpose is a moving-coil d'Arsonval type instrument in which the field magnet is replaceable by the magnets to be tested. The moving coil in series with a suitable resistance is energized from a source of constant voltage. In commercial practice a knowledge of the relative and not of the absolute field strength is required and the scale of the magnet tester may therefore be graduated in convenient arbitrary units. Moreover, a red line is usually marked at an appropriate point on the scale to indicate at a glance the performance aimed at. If the needle of the instrument tends to deflect in the opposite direction it shows that the polarity of the magnet is reversed. It is usual to mark the north pole of each tested magnet with the deflection or field strength figure.

Permanent magnets with small air-gaps, for example, bottle-shape magnets which are largely employed in integrating meters and instruments for damping purposes, are commercially tested by rotating an aluminium disc with a certain impetus between the jaws of the magnet, and then measuring the amount of its travel or the time taken before coming to rest.

Finally, a small magnetic compass is very useful in industrial practice for the purpose of detecting the presence and the direction of stray magnetic fields. For example, switchboard instruments of the dynamometer type may read in error if the cast iron or pressed steel case in which they are mounted becomes for some reason magnetized or "polarized."

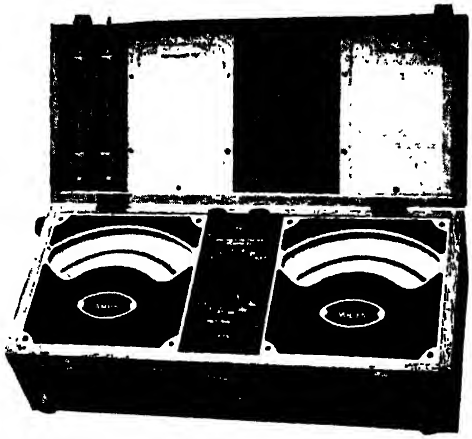
TESTING SET & TESTING INSTRUMENTS

By C. L. Lipman, A.M.I.E.E.

This section deals with testing instruments used for direct and alternating current measurements, the preceding article being concerned with insulation, joint and magnetic tests. For insulation testing sets see Megger and Ohmmeter. See also Instruments ; Meters.

Testing sets are designed for the rapid and accurate measurement of electrical quantities such as current, voltage, resistance, etc., and comprise one or more testing instruments, together with all the necessary accessories.

Testing sets are provided with ready means for varying and extending the range of measurement, and at the same time they are light, portable and, in general, self-contained. Testing sets are classified either according to the functions they perform, *e.g.* insulation testing set, power factor testing set, lamp testing set, valve testing set, cell testing set, etc., or alternatively according to the degree of accuracy which they are capable of giving, *e.g.* precision, sub-standard or



TESTING SET. Fig. 1. Standard test set of the double-instrument pattern.
Elliott Bros. (London), Ltd

commercial grade testing sets by B.S.I. classification.

Some testing sets can be used on both direct and alternating current circuits, and are known as D.C. and A.C. testing sets; others are only suitable for direct current circuits—D.C. testing sets, or for alternating current circuits—A.C. testing sets.

D.C. Testing Set. A typical sub-standard grade testing set for the measurement of direct current and voltage is illustrated in Fig. 1. It consists of two moving-coil instruments mounted in the same case, thus possessing the advantage of enabling simultaneous observations of current and voltage to be made.

The instruments are dead beat and are provided with a metal mirror to enable accurate readings without parallax to be taken.

The current shunts, which are designed with a view to convenience in connecting up, are arranged in one side of the carrying case, the two instruments and the voltmeter resistances in the other.

The movements are shielded from stray magnetic fields. The usual range of such a set is from a few millivolts to 600 volts, and from a few milliampères up to 600 ampères.

The testing instrument illustrated in Fig. 1, page 1,254, is another example. The apparatus is somewhat simpler, having only one measuring element, but it possesses the disadvantage that no simultaneous readings of current and voltage are possible.

A.C. Testing Set. A diagram of a first grade testing set for A.C. commercial measurements, comprising an induction type ammeter, voltmeter and wattmeter with long circular scales and a moving-iron type power factor meter with complete 360 degree scale is illustrated in Fig. 4*a*, *b* and *c* on the Plate. The current and voltage ranges can be extended by means of suitable multi-range current and voltage transformers. The set is particularly suitable for testing A.C. motors, refrigerators and domestic appliances.

In practice, when a case of trouble arises, the ability to make a complete analysis of the circuit conditions is very helpful. A knowledge of the power factor, power, direction of power flow, current and voltage leads to a quick solution of the problem under investigation. Similar sets are available for use on polyphase circuit. with balanced or unbalanced loads. The set can be left in circuit under full load continuously.

The power factor meter offers a ready check on the wattmeter, ammeter and voltmeter readings. The single-phase set can be used on one phase of a two-phase 3- or 4-wire circuit, or on a three-phase 4-wire circuit, where the load is balanced. The readings of the wattmeter are then

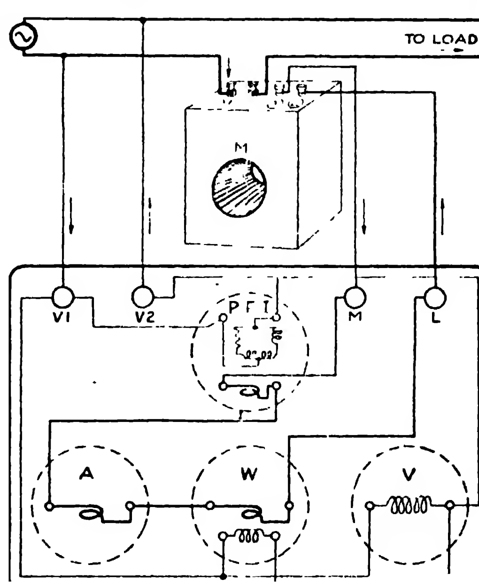
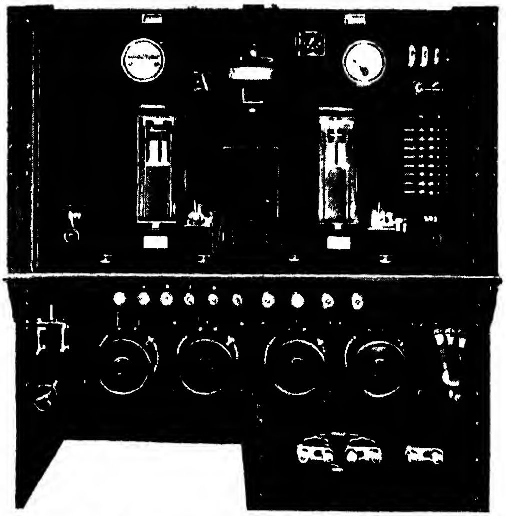


Fig. 2. Diagram of connexions for four-instrument A.C. portable set.
Nalder Bros and Thompson, Ltd.



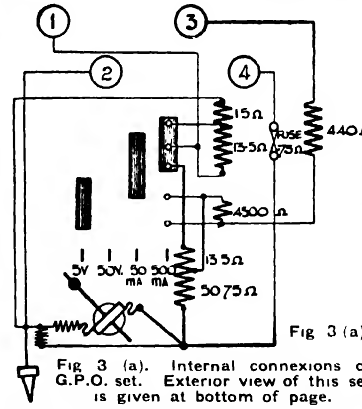


Fig 3 (a). Internal connexions of G.P.O. set. Exterior view of this set is given at bottom of page.

Fig 4 (a). Indicating standard testing set for A C meters (b) Voltage connexions. (c) Current connexions.

Fig. 5. Unipivot dynamometer type portable testing wattmeter

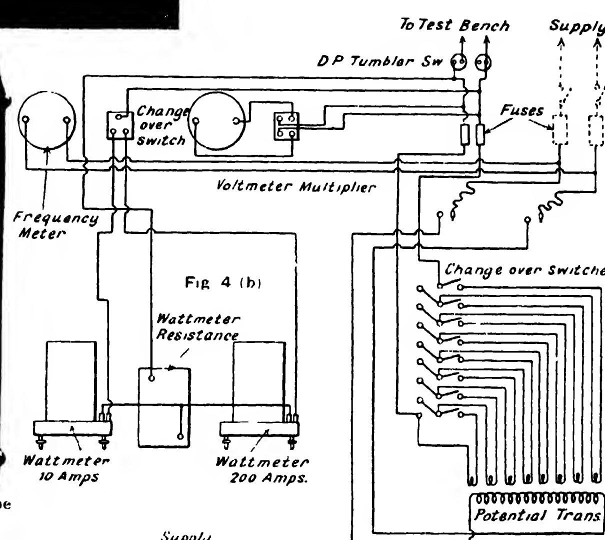


Fig. 4 (c)

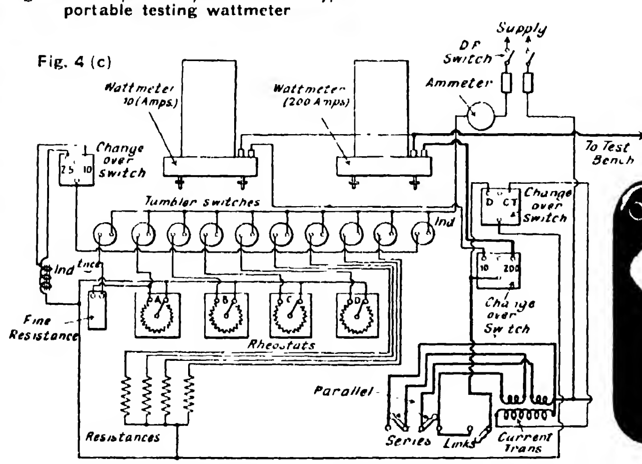
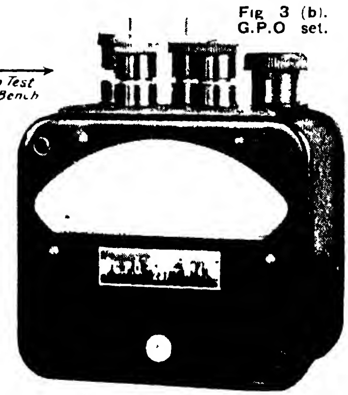


Fig 3 (b). G.P.O set.



TESTING SETS: COMMERCIAL TYPES AND THEIR CIRCUIT DIAGRAMS

Ferranti, Ltd, Salford Electrical Instruments, Ltd, and Cambridge Instrument Co, Ltd

To face page 1258

multiplied by two or three respectively Alternating current testing sets are also made in combinations of three or only two instruments, according to requirements.

D.C. and A.C. Testing Sets. Universal testing sets usually comprise moving-iron ammeters and voltmeters and dynamometer type wattmeters. Moving-coil instruments can also be used on alternating current circuits in conjunction with suitable rectifying devices.

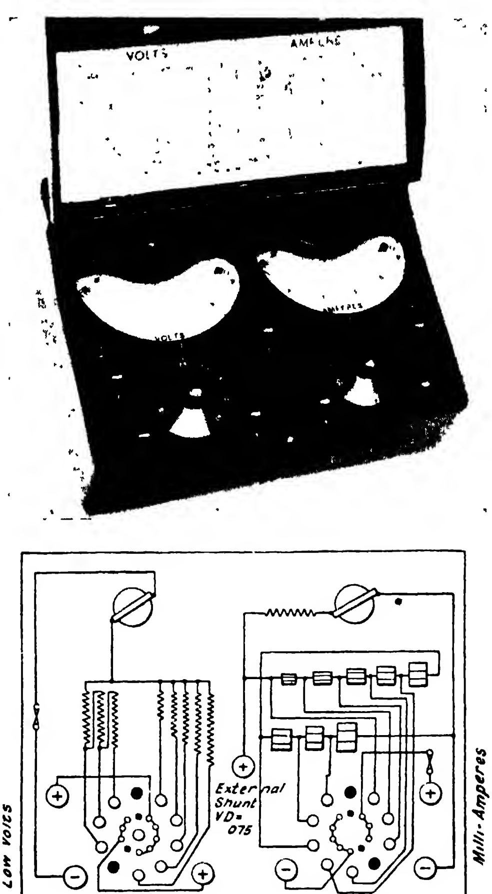
A typical example is the so-called " G.P.O. Detector No. 4," illustrated in Fig. 3 on the Plate. This is a miniature test set specially designed to the British Post Office Engineering Department's requirements for general cable, line, telegraph, telephone and supply testing. The terminals and the range-changing switch are mounted on the bakelite top of a sheet iron case. The internal wiring diagram is illustrated in Fig. 3*a*. The movement is standardized for 10 milliampères at 100 millivolts, and the resistance of the voltage ranges is 100 ohms per volt. External resistances are made up in 100-volt units and are screwed on to terminals 2 and 3 to extend the voltage ranges of the instrument. External shunts are used between terminals 2 and 4 for currents above 500 milliampères.

In order to render the instrument suitable for A.C. measurements a separate rectifier unit is supplied for connexion to terminals 2 and 4 of the indicator. The rectifier attachment has three ranges—15 M.A. and 150 and 300 volts.

The limitation of a rectifier type instrument is that it will read correctly only if the wave form is sinusoidal. Moving-iron ammeters and voltmeters must therefore be used for the correct measurement of R.M.S. values of currents and voltages of peaky wave form obtaining when magnetically saturated iron is present in the circuit under test.

Lamp Testing Instruments. These are designed for the rapid testing of incandescent lamps and consist usually of a voltmeter and wattmeter mounted in one case. The movement is of the dynamometer type for use on D.C. or A.C. and is fitted with efficient air damping, rendering it dead beat. The instrument is housed in a teak case, with leather strap handle and fitted with lamp holder, fuse, length of flexible lead and plug. It is spring controlled and can therefore be used in any position. The lamp testing wattmeter is often provided with two voltage and two current ranges, enabling lamps of all sizes to be tested.

Cell Testing Voltmeter. For the rapid measurement of the E.M.F. of wet and dry cells and the determination of the polarity of their terminals. The instrument is of the moving-coil dead beat type arranged for either side or centre zero scale and designed for accurate readings when used in any position. The following are typical ranges: 3-0-3 volts; 15-0-15 volts; and 0-30 volts. The cast aluminium case is heavily coated with bright black acid-proof enamel. The complete cell



TESTING SET. Fig. 6. D.C. combined voltmeter and ammeter testing set. Above exterior of set with cover raised. Below diagram of internal connexions.
Ferranti, Ltd

testing voltmeter includes contact spears and about 3 feet of a rubber insulated flexible lead.

TETRODE. Alternative name for four-electrode valve (*q.v.*).

THEATRE MAIN. When an independent source of power supply was available it was drawn upon by theatres and other places of entertainment in accordance with the requirements of the L.C.C. and other local authorities for secondary lighting and power, in the event of failure of the ordinary supply. This secondary supply was provided by special mains generally spoken of as theatre mains, coupled up to independent generators. Completely independent sources of supply have now generally ceased to exist and the official requirements are met by the methods described under the heading Emergency Lighting.

THERMAL MAXIMUM DEMAND INDICATOR. A thermal M.D.I. is used for measuring maximum kVA demand in an A.C. circuit, and to all intents and purposes it is a maximum reading thermometer scaled in ampères. *See* Maximum Demand Indicator.

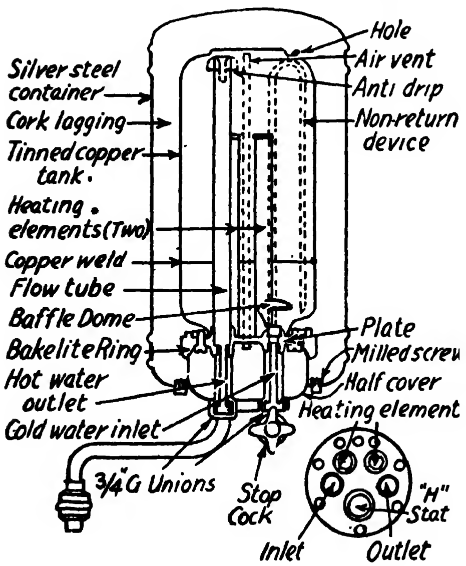
THERMAL OVERLOAD RELEASE. *See* Overload Relay.

THERMAL STORAGE FOR WATER AND COOKING

By L. J. Luffingham

The heating methods considered in this section are distinguished by their economical basis, the main purpose being to spread the load in both water heating and cooking. For the ordinary methods, see Cooking; Heater ; Immersion Heater ; and the general sketch under Water Heating.

In general, electrical energy cannot be economically stored as such. In some applications, however, where electricity has to be converted into heat it is practicable to effect the conversion and store the thermal energy thus released. This is done in thermal storage hot water installations, in the thermal storage type cooker, and sundry industrial applications. The essential advantage of the system is that it allows electrical energy to be used as and when convenient to supply the heat storage reservoir, while the heat supply can be drawn on as and when convenient to the purpose being served. The important economic advantage of this lies in the fact that electricity can (commonly) be purchased much more cheaply under conditions which do not increase the peak demand.



THERMAL STORAGE. Fig. 1. "Sadia" 1½-gallon water heater. *Aidas Electric, Ltd.*

There are two classes of thermal storage installations for domestic hot water supply: (1) the self-contained tank or heater; and (2) conversions of existing hot-water installations to electric heating. A typical heater of the first class is shown in section in Fig. 1. It comprises an inner storage tank, fitted with low loaded immersion heater (*q.v.*), automatic thermostat controlling the electricity

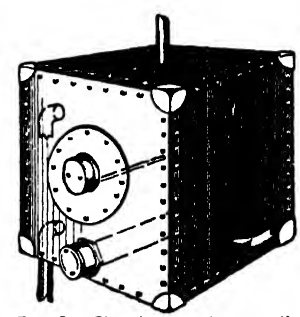
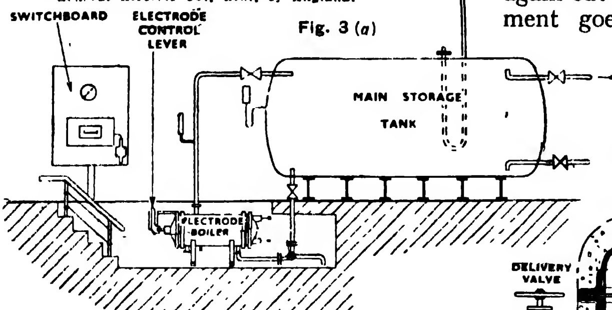


Fig. 2. Sketch showing application of immersion heater to conversion installation. Tank should be lagged.

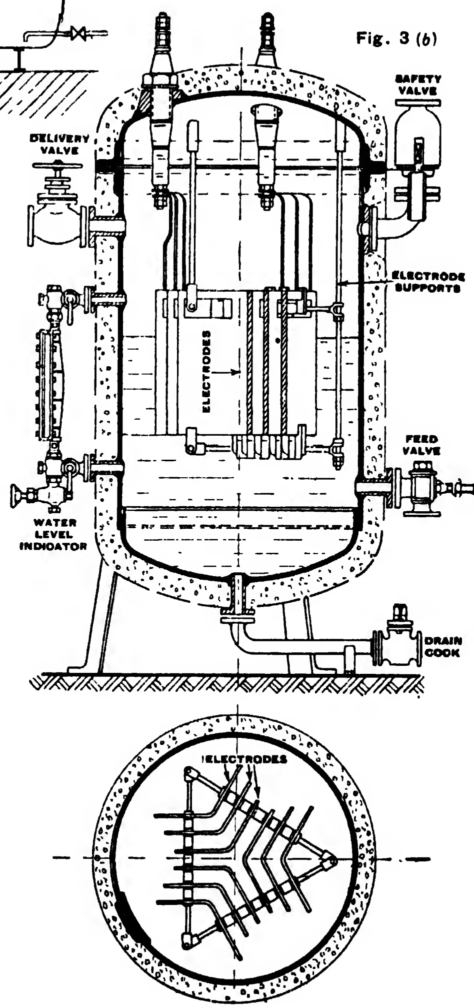
THERMAL STORAGE. Fig. 3. (*a*) Heating circuit arrangement with boiler below level of storage tank. (*b*) Low-tension steam generator in section.
General Electric Co., Ltd., of England.



supply, a wall of heat-insulating material completely surrounding the container, an outer case, and the necessary cold and hot water pipe connexions, taps, etc.

Operation is entirely automatic. Assume the tank full of hot water and the thermostatic switch cut off; then, when hot water is drawn off, a corresponding volume of cold water enters at the bottom. With a properly baffled entry this will not mix to any extent with the hot water remaining, but it will affect the thermostat and current will be switched on. As soon as the fresh cold water has been raised to the pre-set temperature, the thermostat will again cut out. This automatic replenishment goes on continuously, day and night, giving an ever-ready supply of domestic hot water.

Electric water heaters of this



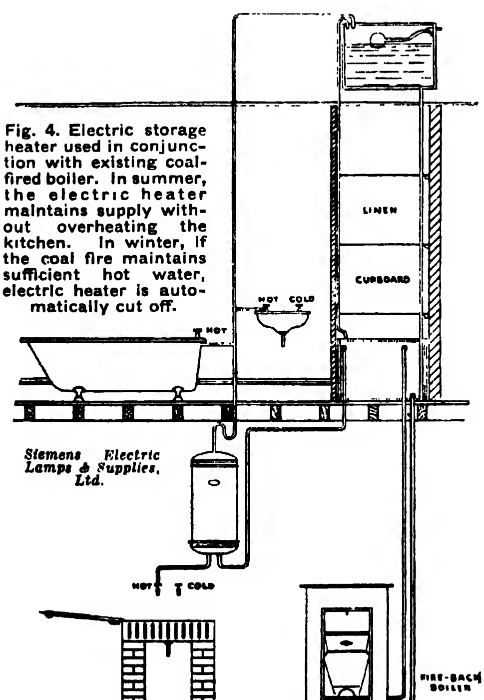


Fig. 4. Electric storage heater used in conjunction with existing coal-fired boiler. In summer, the electric heater maintains supply without overheating the kitchen. In winter, if the coal fire maintains sufficient hot water, electric heater is automatically cut off.

Siemens Electric Lamps & Supplies, Ltd.

type are made in a range of sizes from $1\frac{1}{2}$ gallons up to 30 gallons, and larger. As a rough guide, 500 watts loading is used in the smaller sizes; 1 kW for 10 gallons, increasing pro rata 100 watts per gallon. Various patterns are made, such as the "push-through" type for single points of supply; pressure and semi-pressure types for multiple supply points; self-contained heaters with their own cold water cistern,

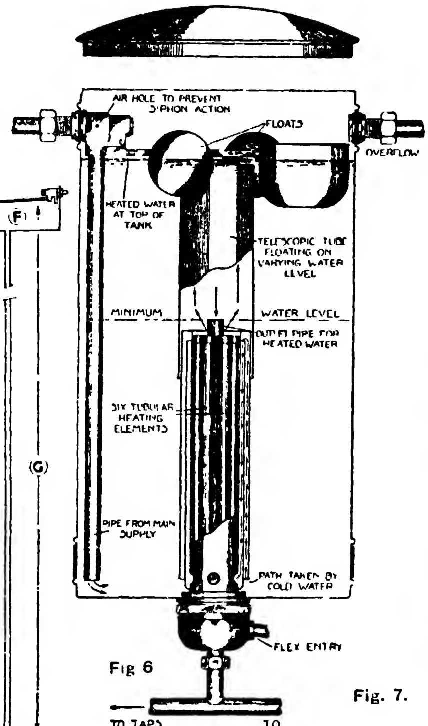
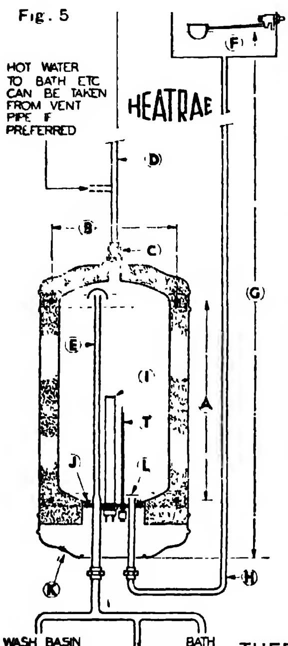


Fig. 6. Diagrammatic section of semi-pressure storage water heater, acting with almost the speed of a geyser.
Santon, Ltd



THERMAL STORAGE. Fig. 5 internal construction and lay-out of water heater. C is union for expansion pipe connexion ; D, expansion pipe ; E, additional hot water outlet , F, cold water ball valve tank; G, head of water ; H, cold water feed ; I, immersion heater ; J, removable bottom plate for cleaning ; K, cable inlet brush , L, baffle for spreading cold water ; T, thermostat.
Electric Fires, Ltd

Fig. 7. Circulator with lagged pipe and jacketted cylinder.
P. Higson & Company

for direct connexion to the water main ; night-time heaters, taking electricity at night-time only; and lagged and unlagged tanks arranged for manual control.

A conversion hot water installation is shown in Fig. 2. In this an electric immersion heater, with thermostat, is inserted in the existing domestic hot water tank. The tank must be heat insulated to prevent loss of heat, or very inefficient operation may result. Operation is automatic as described above, or by manual switching, in which case electricity is switched on when it is desired to heat up the water, as for a bath. The latter arrangement effects economy in energy consumption, but does not give continuous hot water service, as with automatic control. Conversion installations (and also pressure type self-contained tanks) can be arranged to work in conjunction with existing saddle-back and independently fired boilers, no electricity being consumed when the latter are in operation. Broadly speaking, this gives fuel-fired hot water service in the winter and electric hot water service in the summer, a convenient and economical arrangement.

In substitution of plain immersion heaters, circulators are frequently employed. These are available in a wide variety of designs, the basic idea being that water in the immediate vicinity of the immersion heater is kept from mixing with the remainder of the water in the storage tank by cylindrical or other baffles, and is delivered at full temperature straight to the top of the tank. It can then be drawn off immediately for use. In this way hot water, in small quantities, can be had quickly a few minutes after switching on electricity, even though the rest of the water in the tank is cold.

Thermal storage hot water installations, are also used in industrial and commercial applications for hot water supply, heating buildings, and so forth. Loadings of

THERMAL STORAGE. Fig. 7. "Magnet" heat storage cooker. Top, the bifurcated cast iron heating block with one of the withdrawable heaters in position

several hundred kW's are not uncommon, and in some of the largest installations supply is given at extra high tension and utilized in electrode-type boilers, with calorifiers and large storage reservoirs.

Thermal Storage Cooker. In the application of thermal storage to electric cooking a block of iron, weighing 2 cwt., is utilized as the heat reservoir. This has embedded in it an element of 500 watts loading, which is kept in circuit, practically continuously, day and night. The iron block is surrounded by thick heat lagging on all four sides, is covered on top by a similarly lagged hinged lid, the underside being left unlagged and constituting the top element of the oven. An adjustable baffle is fitted to prevent the top heat in the oven being too fierce. A normal 500-watt bottom element is provided in the oven, with switch control so arranged that when the bottom element is switched on for cooking requirements the heat storage block element is switched off, and *vice versa.* In this way the maximum demand of the cooker can never exceed 500 watts, a point designed to appeal to supply authorities, as is also the steady, continuous 24-hour load.

The heat input to the storage cooker is so proportioned as to cover all cooking requirements throughout the day, including all losses, and to restore the cooker to full working capacity during the night. Boiling operations are carried out on top of the storage block, the lid being raised for the purpose, and one big advantage enjoyed by the thermal storage cooker in comparison with the normal type is very quick boiling, particularly first thing in the morning when the block is at maximum temperature. To get the best out of the thermal storage cooker its manipulation technique must be studied; it will then give satisfactory everyday service.

Commercial success of the thermal storage cooker depends to a considerable extent on supply authorities being willing to offer a lower tariff when it is used than is available for ordinary type cookers. The very favourable nature of the demand is justification for that practice. Otherwise the thermal storage cooker will cost more to operate than an orthodox model, the consumption being 12 units per day; about three units a penny is an economic price. On the other hand, in rural areas, and in general where supply lines are light, a cooker with a maximum demand limited to 500 watts has obvious advantages.

THERMIONIC AMPLIFIER. Term sometimes used in wireless for a three-electrode valve used as an amplifying valve. *See* Amplifier; High-frequency Amplification; Low-frequency Amplification; Valve.

THERMIONIC CURRENT. The current which passes between the electrodes of a vacuum tube with heated cathode, such as a wireless valve. In its strictest sense it refers to the current in a valve in which traces of gas have been left, *i.e.* a soft valve, in which case the electrons emitted from the cathode collide with the gas molecules causing the ionization of the gas. In this state it acts as a conductor of electricity between anode and cathode.

But in modern receiving valves all possible traces of gas are removed from the bulb and the current passing between

the electrodes is in the form of streams of free electrons. The term thermionic current has come to be general, applied to this case also, even though there are no gas ions present.

Any conductor when heated above a certain temperature throws off free electrons, this happening when the molecular agitation is sufficiently great to cause the electrons to break through the surface tension of the conductor. The temperature at which emission commences depends on the material, and in modern valves a suitable choice is made to give free emission at the lowest temperatures possible. For a comparison, the operating temperatures of cathodes employing three classes of materials are given :

(a) Pure tungsten, 2,400 to 2,500 degrees absolute.
(b) Thoriated tungsten, 1,800 to 1,900° abs.
(c) "Oxide" coated, 1,100 to 1,300° abs.

The oxides referred to are those of barium, strontium and calcium, these being coated on the surface of a metal such as nickel or molybdenum. *See* Cathode ; Space Charge ; Valve.

THERMIONIC VALVE. An ionic valve in which the source of free electrons is an electrode maintained at a suitable temperature by external means. A valve having two electrodes is sometimes called a diode ; one with three electrodes a triode ; and one having four electrodes a tetrode. *See* Anode ; Grid ; Valve.

THERMO-ELECTRIC COUPLE. Seebeck employed a copper-bismuth junction in his original discovery of the thermo-electric effect. Later he extended the experiment to other metals, and finally arranged a table of metals in thermo-electric order as follows : Antimony, arsenic, iron, zinc, gold, silver, platinum, copper, lead, tin, nickel, cobalt, bismuth. This order only holds good for certain limits, and the structure of the metals, etc., must be taken into account. Bismuth and antimony, being farthest from each other in the list, are best for the construction of thermo-electric combinations of pure metals.

The actual electro-motive force of a thermo-electric couple is very small when compared with that of a primary cell. In the following table the metals are arranged in the reverse order to that just followed, and in the adjacent column is given the E.M.F. developed with each of these metals, and lead as a standard metal. The difference of temperature required to develop these E.M.F.'s is 100°, one of the junctions being cooled with melting ice (0° C.), and the other heated with boiling water (100° C.).

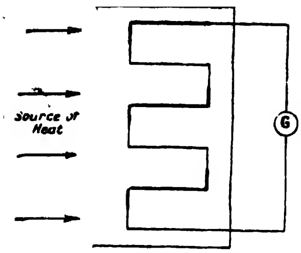
THERMO-ELECTRIC PROPERTIES OF THE METALS

Metal	Voltage when paired with lead between 0° and 100° C.
+Bismuth	+ ·00682 volts
Cobalt	+ ·00320 ,,
Nickel	+ ·00246 ,,
German silver ..	+ ·00148 ,,
Platinum (soft) ..	+ ·00012 ,,
Aluminium	+ ·00006 ,,
Tin	+ ·00001 ,,
Lead	—
Copper	− ·00017 ,,
Platinum (hard) ..	− ·00022 ,,
Silver	− ·00029 ,,
Gold	− ·00033 ,,
Zinc..	− ·00035 ,,
Iron..	− ·00149 ,,
−Antimony	− ·00463 ,,

In this table the positive sign indicates a current from the metal to lead across the hot junction. For any two metals in the table the E.M.F., under similar conditions of temperature, may be found by subtracting algebraically the voltage of the metal lowest down from that of the one above it. For the bismuth-antimony combination this gives ·01145 volt, or about $\frac{1}{100}$th of the E.M.F. of a Daniell cell.

Alloys may be used for thermo-electric purposes, and with some of these much larger E.M.F.'s are developed than with the pure metals. The position of various alloys in the thermo-electric series does not, moreover, follow the order which might be expected from the thermo-electric position of the metals whence they are formed.

The Peltier effect enables us to trace out the source from which the energy of a current flowing in a thermo-electric circuit is derived, for it is found that the direction of the current across the heated junction of the circuit is that which gives a cooling Peltier effect. We have, therefore, the



THERMO-ELECTRIC COUPLE. Fig. 1. The junctions are arranged in such a manner as to multiply the effect of one junction.

current which is set up cooling the hot junction, whilst the external source of heat is supplying heat tending to keep up the temperature. Some of the heat energy supplied is therefore transformed to electric-current energy at the hot junction. At the cold junction, as a rule, the opposite effect takes place. The Peltier effect here is a heating effect, and some of the electric energy is thereby transformed back again to heat. Following a very general law, we see that the current flow tends to destroy the temperature difference which is necessary to maintain it.

Thermo-electric Inversion. If a thermo-electric couple of two metals, say copper and iron, be taken, and whilst one of the junctions is kept at 0° C., the temperature of the other junction is gradually raised, it will be found that the current generated gradually increases to a maximum, and then decreases until at a certain temperature of the hot junction the current ceases altogether. If the temperature of the hot junction be raised still higher, the current is again set up, but in the opposite direction. This phenomenon, known as thermo-electric inversion, was discovered by Cumming in 1823. Subsequent investigation has shown that when the current in such a circuit is a maximum there is no Peltier effect at the hot junction. Above this temperature the Peltier effect is reversed. The temperature at which the Peltier effect disappears for any pair of metals or alloys is the thermo-electric critical temperature for those materials.

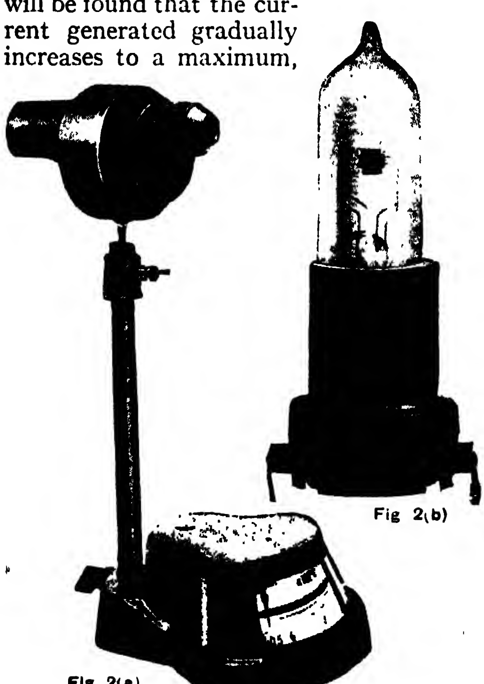


Fig 2(b)

Fig. 2(a)

Fig. 2. (a) Sensitive form of modern thermopile. (b) Thermo-electric couple sealed in glass bulb, as used in (a).
Elliott Bros. (London), Ltd.

Thermopiles. Thermo-electric batteries, or thermopiles, can be built up of strips of two dissimilar metals placed alternately in the circuit as shown in Fig. 1. As the junctions have to be alternately heated and cooled, care must be taken that the odd junctions are on one side and the even junctions on the other. If the former be heated and the latter cooled, on closing the circuit a current will be produced due to the thermo-electric E.M.F. generated by the arrangement.

To increase the E.M.F. of the pile, it is necessary either to increase the temperature difference or to increase the number of junctions. Fortunately, the general conditions are such as to render compact arrangements of numerous junctions possible. Fig. 2 illustrates a sensitive form of modern thermopile as manufactured by Elliott Bros. (London), Ltd.

A sensitive thermopile may act as a receiver to detect the heat energy of a light beam, a low-resistance telephone being connected in place of the galvanometer. The thermopile must have a very small heat capacity if the heat energy of a beam of light which falls upon it is being measured, the latter being vibrated by means of sound. But such a receiver has only a scientific interest, being considerably less sensitive than the selenium cell.

Pyrometers. The thermo-electric effect is also extensively applied to the measurement of the high temperatures attained in furnace work. Various types of these highly efficient instruments will be found described under the heading Pyrometers (*q.v.*). *See* Peltier Effect; Selenium Cell.

THERMO-GALVANOMETER. Type of sensitive galvanometer which makes use of a thermo-couple to measure small alternating currents. The best known type of thermo-galvanometer is that devised by Duddell. The alternating current passes through a heater, near to which is placed one or more fine thermo-junctions, and the rise in temperature due to the current is indicated on a moving-coil galvanometer having a high volt sensitivity. The deflections of the galvanometer are virtually proportional to the square of the current through the heater. The instrument has practically no self-inductance or capacity, and can therefore be used on a circuit of any frequency, while currents as low as twenty microampères may be readily measured. It can be accurately standardized by continuous current, and can be used on circuits of any wave form; it has a short period, and is very dead beat.

THERMOMETER. All thermometers may be calibrated to read directly in any of the three customary scales of temperature, namely, Fahrenheit, Centigrade, and Réaumur. For purposes of conversion it is useful to remember that 9° F. = 4° R. = 5° C. In converting C. and R. degrees into F. degrees it must be noted that 32° are to be added to the result of multiplication and *vice versa* for inversion, 32 must be subtracted before effecting division, *i.e.*

$$C = \frac{5}{9}(F - 32) \text{ or } F = \frac{9C}{5} + 32, \text{ whilst } R = \frac{4C}{5}$$

RELATION OF THERMOMETER SCALES

Centigrade	Réaumur	Fahrenheit	Centigrade	Réaumur	Fahrenheit	Centigrade	Réaumur	Fahrenheit
−17·7	−14·2	0	20	16	68	115	92	239
−15·0	−12·0	5	25	20	77	120	96	248
−10·0	− 8	14	30	24	86	150	120	302
− 5	− 4	23	35	28	95	200	160	392
0	0	32	40	32	104	250	200	482
1	0·8	33·8	45	36	113	300	240	572
2	1·6	35·6	50	40	122	350	280	662
3	2·4	37·4	55	44	131	400	320	752
4	3·2	39·2	60	48	140	1,000	800	1,832
5	4	41	65	52	149	2,000	1,600	3,632
6	4·8	42·8	70	56	158	3,000	2,400	5,432
7	5·6	44·6	75	60	167	4,000	3,200	7,232
8	6·4	46·4	80	64	176	5,000	4,000	9,032
9	7·2	48·2	85	68	185	6,000	4,800	10,832
10	8	50	90	72	194	7,000	5,600	12,632
12	9·6	53·6	95	76	203	8,000	6,400	14,432
14	11·2	57·2	100	80	212			
16	12·8	60·8	105	84	221			
18	14·4	64·4	110	88	230			

RELATIVE VALUES OF DEGREES

Centigrade	Reaumur	Fahrenheit
1	0·8	1·8
2	1·6	3·6
3	2·4	5·4
4	3·2	7·2
5	4	9

The above table enables a comparison of any temperature on the three scales to be made at a glance. *See* Galvanometer.

THERMOPILE. *See* Thermo-electric Couple.

THERMOSTAT AND THERMOSTATIC CONTROL

By R. A. Baynton, B.Sc. (Eng.), A.C.G.I.

One of the many departments in which the flexibility, accuracy and dependability of the electric method is unapproached by any other is here considered. A great variety of applications of control by temperature switches, both industrial and domestic, are mentioned, and the principal forms of thermostatic apparatus described.

For many purposes it is essential to maintain the temperature constant at a given value or within given limits, and for many others it is a great convenience to be able to do so. It is not possible, however, to maintain the temperature constant at a desired value for long periods of time without some form of automatic control. An instrument that performs this service is termed a thermostat.

The underlying principle of all forms of thermostatic control is the same. The

controlled temperature is allowed to fluctuate between a maximum and a minimum value, the difference between these being known as the "differential" of the thermostat. The smaller the differential the closer is the control. When the temperature exceeds the predetermined maximum, the supply of the fuel or energy to the heater is cut off or reduced. When, as a result, the temperature falls below the minimum value permissible the supply of fuel or energy is restored. A thermostat thus consists essentially of two distinct parts, that which responds to changes in temperature and that which controls the supply of fuel or energy, and is dependent on the former. Usually the thermostat is affected by the temperature of its immediate surroundings, but certain types respond to radiant heat.

Of the various forms of thermostat available only those which control the supply of energy by electrical means are described below. When electrical heating is employed the regulation may be effected by the switching on or off of the supply, or by the variation of the resistance, or inductance in series with the heater, the former method being the more usual. The fuel supply of oil and gas fired furnaces may be regulated by magnetically operated valves, oil-burner relays, and fractional H.P. feed motors, and coke or coal fired furnaces may be regulated by adjustment of the ash-pit and check dampers, by controlling the feed water, and, where the stoking is mechanical, by regulation of the supply of solid fuel.

Among the numerous industrial applications may be mentioned the temperature control of baking and process ovens and stoves (*e.g.* for japanning and enamelling), annealing furnaces, flue temperatures, process tanks and vats, metal-pots, and calorifiers. Thermostats are also employed for regulating the air temperature of rooms and buildings (sometimes called space-heating), for central heating installations, immersion heaters and storage tanks for domestic purposes, and the oven temperatures of electric cookers. No one thermostat is suitable for all the applications mentioned above, and many types have been developed.

The temperature sensitive portion of the thermostat, which actuates, either directly or through suitable levers or toggle-joints, the main or pilot contacts of the circuit controlling the heater, may consist of any one of the following: two rods with unequal coefficients of expansion (metal expansion stem); a bimetallic strip, spiral or helix; a "bourdon" tube filled with a sensitive liquid, vapour, or gas; a flexible diaphragm or bellows, filled with some easily vaporizable liquid, such as ethyl chloride; or a thermo-couple; or a resistance bridge.

The switch contacts of these instruments, which are in continual operation, need to be carefully designed to prevent them from becoming defective after a short period of service. Where loads of more than a few hundred watts have to be broken the contacts must have a quick make and break action, either through toggle-joints or by employing some form

Fig 1

Fig 2

THERMOSTAT. Fig. 1. "Drayton" temperature-operated electric switch. Fig. 2. "Satchwell" room thermostat for factory heating control.

Drayton I . . Instrument Co . . . Rheostatic Company, Ltd

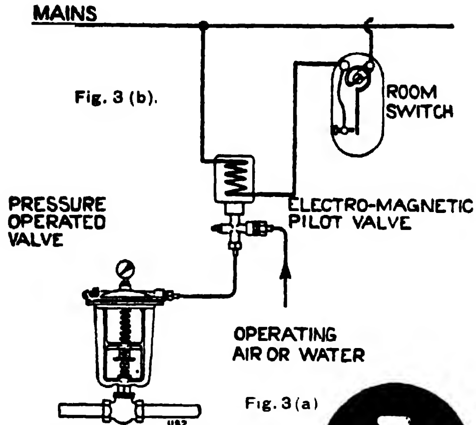
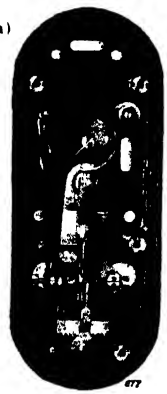


Fig. 3(a)



THERMOSTAT. Fig. 3 (a and b). Drayton room switch (right), and (above) schematic arrangement for hydro or pneumatic-electric control.

of magnetic snap-contact, such as that shown in Fig. 3. To reduce the wear still further, heavy contacts should be employed; the Drayton Regulator Co. for this service employ large diameter discs of silver-gold alloy embedded in heavy copper studs, so that a high resistance to wear is combined with good heat conductivity. Such contacts are suitable for capacities up to 15 amps., 250 volts on A.C. circuits, but for D.C. circuits, which maintain a destructive arc more readily, they are suitable only for currents up to 1 amp.

To control D.C.circuits carrying currents greater than 1 amp., a relay may be used with a snap-contact thermostat, or a mercury-in-glass switch (*see* Mercury Switch) may be included in the thermostat. These switches are suitable for controlling both A.C. and D.C. circuits up to 15 amps., 250 volts,and unless subjected to very heavy or periodic shocks are perfectly reliable. The switching may be so arranged that contact is either made or broken on increasing temperature, or made on both increasing and decreasing temperatures.

A thermostat depending on the unequal expansion of two metallic rods is shown in Fig. 1. This type is suitable for inserting through the walls of water heaters, ovens, ducts, furnaces and process heaters, and is obtainable in a number of different ranges up to 1,800° F. The length of the tube depends on the maximum temperature to be controlled, the scale range being inversely proportional to the length of the thermostat, as are the differentials, which with this type of instrument are comparatively large, being with some instruments, although not of that illustrated, as much as 25° F. The instrument illustrated has a snap-action switch, and loads up to 10 amps., 250 volts A.C., may be wired direct to the switch. For D.C. the switch should be used only for light pilot circuits not exceeding 0·5 amp.

Long thermostats should be used for the control of air temperatures, and if the air velocity past the thermostat is low the tube should be fitted with fins. Thermostats should never be used above 1,000° F. without protecting pockets made from suitable material, according to the medium in which they have to work. Above 1,000° F. thermostat sheaths have a very limited life, and it is advisable to keep spares. For controlling type-metal melting pots and for similar applications an offset model is obtainable.

For immersion water heaters this form of thermostat frequently forms part of the same head as the heater blades or core. Thermostats operated by helical bimetallic strips, enclosed in cylindrical protective tubing, are rather similar in appearance.

The form of thermostat illustrated in Fig. 2 is suitable for regulating the temperature of rooms

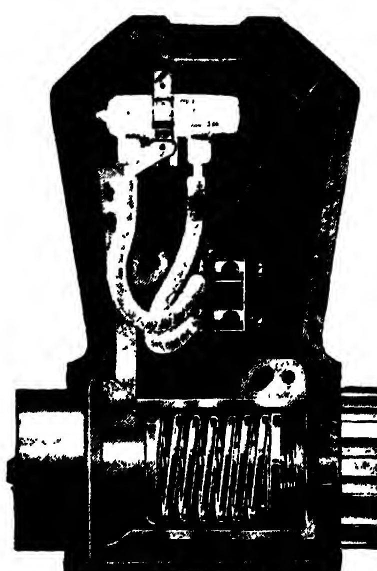


Fig. 4. A pressure thermostat operating a mercury switch.
Unity Heating, Ltd.

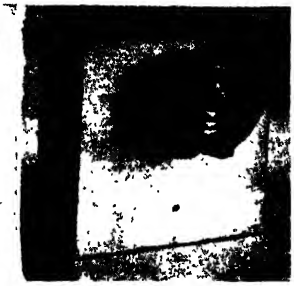


Fig 6. An alarm thermostat.

THERMOSTAT. Fig. 5. A Unity radiation thermostat Fig. 7. A differential expansion instrument.
Salford Instruments, Ltd. & Unity Heating Ltd.

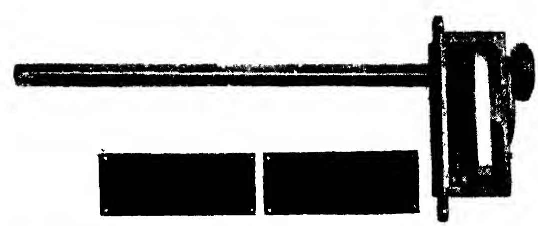
in which the heat losses are normal, and the temperature of the air in bulk is raised. It consists of a spiral or thermostatic bimetal enclosed in a case perforated to permit free circulation of air, which ensures a rapid response to changes in temperature. Such instruments, which should be mounted about seven feet from the floor and out of the direct path of heat rays, have a differential of about $1\frac{1}{2}°$ F., and may be pre-set to any desired room temperature. In the reverse view of the "room-switch" shown in Fig. 3 (*a*), the small but extremely powerful biassing magnets of the snap-contact switch can be seen clearly. A circuit diagram illustrating the application of this and similar instruments to the control of central heating installations, through an electro-magnetic pilot valve, is shown in Fig. 3(*b*). A thermostat for regulating room temperatures, which is operated by a pressure cell, consisting of copper bellows filled with ethyl chloride, is shown in Fig. 4.

A mercury-in-glass switch will be seen at the top of the instrument. Vapour pressure thermostats are very sensitive and develop a high mechanical force but have a limited temperature range.

For controlling air temperatures in enclosures, where heat losses are abnormally high, and which for this reason are warmed by radiant heat, a radiation thermostat such as that shown in Fig. 5 is suitable. This form of instrument must be so mounted that it is not screened from either radiant or convective effects. It is suitable for voltages between 100 and 250 A.C., but must be used with a relay.

When public buildings or blocks of flats are warmed by central heating, it is impossible to control the temperature at every point, and simple thermostats are of little use. For such installations, the Variostat, developed by the Drayton Regulator Co., is recommended. It varies the temperature of the whole heating system according to outdoor temperature.

THIRD BRUSH CONTROL. Nearly all charging dynamos fitted to car lighting systems are of the third brush type. This may be described as the inherent method of current output regulation, the regulation being accomplished without the use of electro-magnets or a resistance, or of any other external fitment. The salient features of this method of control are indicated in Fig. 1 (on next page) which gives the circuit diagram while in Fig. 2 the third brush is seen.



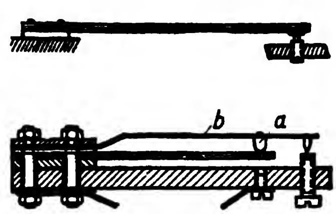
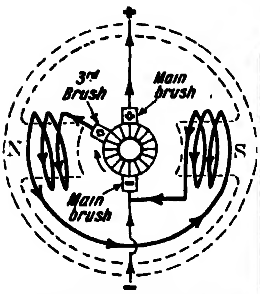
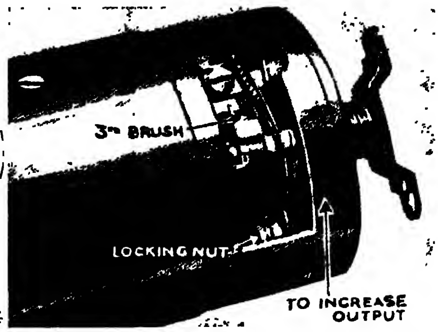


Fig. 8. An oven-type cooker control with quick make and break. Fig. 9. An improved type of regulator: (a) insulating stud attached to (b) current-carrying-strip.
Salford Instruments, Ltd & "The Electrical Review"

The field windings are of the ordinary compound type, and the third brush is connected to the positive end of the shunt winding on the left or north pole side of





THIRD BRUSH CONTROL. Fig. 1 (left). Diagram of motor-car dynamo brushes. Fig. 2 (right). Position of third brush seen in dynamo removed from M.G. "Midget." It is adjusted by slacking the locking nut and by rotating the brush gear, but charging rate with all lights must not exceed 8 ampères

the dynamo. The current collected by the third brush flows through the shunt windings and out to the main negative terminal. As the current flows from the negative brush through the series-parallel armature it is divided, and half flows through one series of armature windings on the left of the figure, and half through the remaining armature windings on the right. As the third brush, which collects positive current, is disposed some way ahead of the main positive brush, only part of the current flowing on the left-hand side of the armature is led through the field windings, that is, some of the armature windings are cut out of the shunt circuit.

As the speed of the armature increases the lines of force produced by the field magnets distort in such a way that the current passing through the field windings diminishes and the field becomes weaker, thus neutralizing the greater current production due to higher speed and maintaining the output virtually constant.

To increase the output the third brush is moved farther away from the main negative brush. Thus a larger number of armature windings between the main brushes are brought into use. The strength of the current passing through the field windings is therefore increased, and the magnetic field becomes correspondingly stronger. Conversely, the dynamo output is reduced when the third brush is moved nearer to the main negative brush, thus reducing the current passed through the shunt field winding.

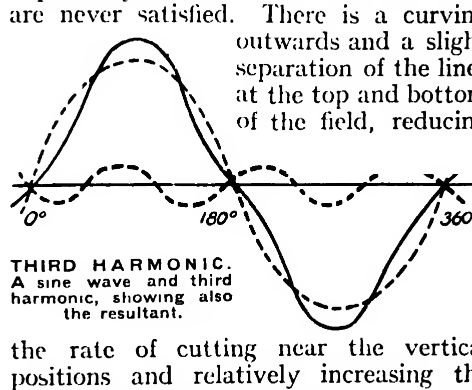
The position of the third brush should be altered very little at a time, as the variations in output for a small adjustment are considerable. *To increase the dynamo output by more than 2 or 3 ampères may cause insulation breakdown.*

Any falling off in the output of a dynamo should never be corrected by adjustment of the third brush unless other possible causes have been investigated. It should first be ascertained whether the commutator is dirty or worn, the carbon brushes are scored, the brush springs weak, or the external connexions loose or dirty.

This method of control is mainly employed for motor-car and train-charging dynamos. *See* Shunt Wound Generator.

THIRD HARMONIC. When a rectangular loop of copper is rotated at a constant speed in a perfectly uniform horizontal magnetic field, a simple sine wave of E.M.F. will be generated in the copper in each complete revolution; *i.e.* the rate of cutting of magnetic lines at each instant will be proportional to the sine of the angle of the position of the loop at the instant, as measured from the vertical position.

In practice, however, the conditions of a perfectly uniform and horizontal field are never satisfied. There is a curving outwards and a slight separation of the lines at the top and bottom of the field, reducing



THIRD HARMONIC. A sine wave and third harmonic, showing also the resultant.

the rate of cutting near the vertical positions and relatively increasing the rate for the same total flux cut at and near the horizontal position. The effect would be slight but distinctly perceptible, if the wave form were analysed, being not so marked but similar to the full curve in diagram. When analysed this curve is found to consist of a principal or fundamental

and simple sine wave, combined with its third harmonic of triple the frequency, but of much less amplitude; these curves are shown by the two dotted lines. The effect of the weakening of the field in the vertical positions of the loop is seen near the points 0°, 180° and 360°.

The case of a modern alternator is necessarily more complicated; but because of the fringing of the field at the pole tips we should expect to find amongst the more complex results an effect similar to the above, namely, the presence of a third harmonic. The existence of these harmonics has an important influence upon the scheme of winding of three-phase machines and modern design has succeeded in limiting their effects and suppressing them to a reasonable minimum. They also need careful consideration in transformer design. *See* Harmonics; Three-Phase System; Transformer.

THOMSON METER. The Thomson meter is a motor type meter, designed for measuring the watt-hours consumed in a D.C. circuit. For further information *see* Meter.

THREE-CORE CABLE. Three-core cables are used for both D.C. and A.C. working. Except for the largest sizes of conductors, three-core cables are preferable to three single-core cables for the following reasons.

They are initially cheaper; easier to handle and to instal; their inductance is less, and in A.C. working the reactive voltage drop is reduced to a minimum; they can be armoured over the sheath without causing either high induced voltage on the armour or alternatively circulating currents in the armour if the latter be earthed at both ends. Current loadings, from the temperature rise point of view, are, however, lower than with single-core cables but, except on very short route lengths, voltage drop usually is more important as the deciding factor in fixing the size of cable to be used, and in this respect the advantage is with three-core cables.

With pressures of 33 kV and over the insulation of 3-core cables is liable to deterioration, due to the direction of the electric stress not being perpendicular to the surface of the core. *See* Cable; S.L. Cable, *etc.*

THREE-ELECTRODE VALVE. Also known as triode; this is the popular name for the most commonly used valve in wireless. The three electrodes are named the filament, the grid, and the anode or plate. *See* Valve.

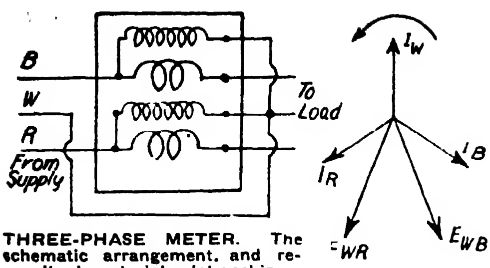
THREE-PHASE. An alternating current system in which the circuit is divided up into three branches or phases, the currents in which are displaced from each other by 120°. *See* Phase; Polyphase.

THREE-PHASE, FOUR-WIRE SYSTEM. This system is the standard now employed in Great Britain for L.T. distribution. Such systems are supplied from double-wound step-down transformers connected either delta-star or star-interconnected-star. The former is the more common. In both cases the star or neutral point (*q.v.*) provides the point for connecting the fourth wire. With a system of this kind, therefore, three-phase loads across lines and single-phase loads from each line to the neutral can be supplied simultaneously. With either transformer connexion cited, the single-phase loads to neutral may be unbalanced without excessive voltage drop, and the neutral wire carries the net out-of-balance current.

A three-phase, three-wire system can be converted to a four-wire system, by providing a three-phase interconnected star balancer in which the three terminals are connected to the line wires, the fourth wire being taken from the balancer neutral. If the single-phase loads to neutral are balanced, no current flows in the fourth wire. The standard three-phase L.T. distribution voltage in Great Britain is now 400 volts, giving single-phase voltages to neutral of 230. *See* Balanced Load; Star Connexion; Three-Wire System.

THREE-PHASE METER. The total energy in a three-phase circuit can be measured by a simple three-phase induction wattmeter having two elements, which act upon a single rotating member. The scheme of connexions of the meter is shown in page 1272, where the instrument is shown connected in a three-phase balanced circuit.

The general circuit loading conditions have an appreciable effect upon the registration of a polyphase meter, on account of a certain interaction arising from the close proximity of the two



THREE-PHASE METER. The schematic arrangement, and resultant vectorial relationship.

elements. On unbalanced loads the speed variations may be as much as 2 per cent. on either side of the correct speed obtaining with balanced loads. The top element current coil is usually connected in the blue line, and the bottom element current coil in the red line; one end of each voltage coil is connected to the same line as its corresponding current coil, while the common connexion is made to the white line. Reference should be made to B.S.S. 37–1929 for Electricity Meters.

THREE-PHASE MOTOR. An electromagnetic machine adapted to receive a three-phase supply of electricity and produce mechanical power.

The time sequence of the separate phases of a three-phase system enables a rotating magnetic flux to be readily produced, and this, by reaction with another magnetic field, can be made to drive motors having very useful characteristics. The second field may be of constant direction, produced by a continuous current electro-magnet (supplied by an exciter), in which case the unidirectional field links with the rotating field and the motor runs at the same speed as the latter, *i.e.* the motor is synchronous. Until the two fields approach coincident speed, however, the torque produced is very small and the current excessive, so that some auxiliary means of starting is necessary. (*See further under* Synchronous Machine *and* Induction Motor.)

The second field may, however, be produced by currents induced in conductors by the action of the first (primary) field. In this case it is essential that the speed of the conductors be different from that of the primary field, otherwise no current will be induced. Hence the speed of such a motor must be less than synchronous speed, and the difference, usually only a few per cent., is known as the slip. This is the principle of the induction motor. *See* Induction Motor.

In the induction motor speed control can be secured by the use of slip-rings and the insertion of resistance in the rotor circuit. As the speed departs from synchronism so the slip frequency rises. The losses in the resistance are considerable, however. By using a commutator as a frequency changing device the energy at slip frequency can be returned to the line at normal frequency. This is the principle of the A.C. commutator motor (*q.v.*), which can be designed to give either a variable-speed characteristic or a constant speed at any load.

Three-phase motors are available for practically every industrial requirement. Induction motors are the most widely used, and the squirrel-cage induction motor (*i.e.* the type without slip-rings) is the commonest and simplest piece of electrical machinery extant.

Reversal of any three-phase motor is achieved by changing over any two-supply wires, thereby reversing the direction of the rotating field. If this be done while an induction motor is running, a heavy current is taken, the motor is quickly stopped and re-starts in the opposite direction. Powerful braking is done by this means on rolling-mill motors, etc., and is termed "plugging."

Three-phase motors would be very suitable for traction purposes were it not for the complications involved in the use of at least two conductor rails or overhead lines. They bid fair to become universal for stationary work of all kinds.

THREE-PHASE ROTOR. The rotors of induction motors fall into two chief classes, namely (a) "squirrel-cage" rotors in which the rotor windings are short-circuited upon themselves, and (b) "wound" rotors in which the conductors are grouped according to a systematic plan and the windings brought out to slip-rings by means of which resistance may be introduced into the circuits or the rotor placed in cascade connexion (*q.v.*). When the windings are placed in three symmetrical sections connected to three separate slip-rings it is known as a three-phase rotor. In such a case the starting resistance requires to be in three sections also, varied simultaneously by

means of a three-arm switch or similar device. *See* Induction Motor; Squirrel-Cage Motor.

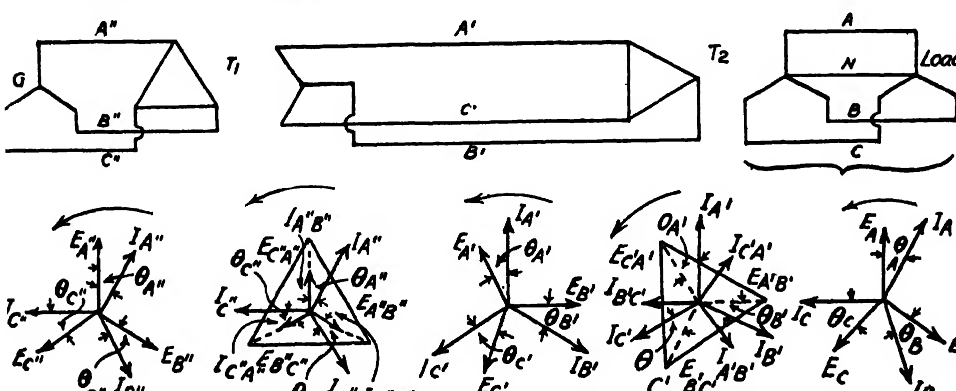
THREE-PHASE SYSTEM. In just the same way as alternating current has demonstrated its advantages over direct current for general power transmission and distribution, so has the three-phase system proved superior to all others for the same purposes. For E.H.T. and H.T. transmission and distribution, three-wire circuits are employed, while four-wire circuits are used for L.T. distribution. A three-phase system may be star or delta connected, and this, of course, refers to the connexion of the source supplying the system, which may be a generator or the secondary of a step-up or a step-down transformer. The star connexion is used in the large majority of cases, as it provides a neutral point for earthing and for loading purposes. The former is important and necessary on all systems, while the latter is usually an essential requirement of L.T. distribution systems. The respective merits of the star and the delta connexions are discussed under Star Connexion (*q.v.*).

Power may be transmitted or distributed in bulk at generated voltage or at higher than generated voltage, and in the latter case delta-star-connected three-phase, three-wire transformers are used for stepping up the generator voltage. For L.T. distribution, delta-star-connected step-down transformers also are employed, with a three-wire primary and a four-wire secondary.

Three-Phase Harmonics. Harmonics are important in three-phase systems and in three-wire circuits, currents of 3rd, 9th, 15th, etc., harmonic orders cannot flow in the line wires, but they can circulate in a closed delta winding such as is formed by delta-connected transformer windings. The 5th, 7th, 11th, etc., harmonic currents can, however, flow in the line wires. In the three-wire star-connected system 3rd, 9th, 15th, etc., harmonics can be present in the line-to-neutral voltage, but not in the line-to-line voltage. In the four-wire star-connected system 3rd, 9th, 15th, etc., harmonic currents can flow in the line wires and the neutral return, thus nearly eliminating the corresponding harmonic voltage components from the line-to-neutral voltages. Similarly, if the star neutral be earthed, 3rd, 9th, 15th, etc., harmonic currents can flow through the lines, the line-to-earth capacitances and the earth.

Cable Systems and Power. Three-phase systems may, of course, consist of overhead lines or underground cables, and the latter may be single-core, three-core or four-core, as best suit the particular circumstances. On H.T. and E.H.T. systems of overhead lines it is essential to transpose the conductors regularly and properly to minimize inductive interference with parallel-running communication circuits. On underground systems of single-core cables transposition improves the electrical and magnetic balance of the power circuit, although communication circuit interference is not a prime factor.

If the neutral point of a three-phase



THREE-PHASE SYSTEM. Vector conditions of voltage and current in a compound series circuit.

system is solidly earthed, no part can reach a potential above earth under fault conditions greater than the normal line-to-neutral voltage. If the neutral is earthed through a current-limiting device the voltage drop across the device under fault conditions acts vectorially to increase the voltage to earth of two of the phases.

The total power in a balanced three-phase system is given by the expression $P = EI\sqrt{3} \cos \phi$, where P is the power in watts, E is the line voltage in volts, I is the line current in amps. and $\cos \phi$ is the power factor of the load current expressed as a decimal of unity. If the load is unbalanced, the total power P is the sum of the powers of the three phases in which, for each phase, the power is $P = (E/\sqrt{3})\ I\ \cos \phi$, where $E/\sqrt{3}$ is the line-to-neutral voltage, I is the line current for the phase concerned and $\cos \phi$ is the corresponding power factor of the load on the phase.

The diagram shows vectorially the voltages and currents in a typical three-phase compound series circuit employing delta-star step-up and step-down transformers.

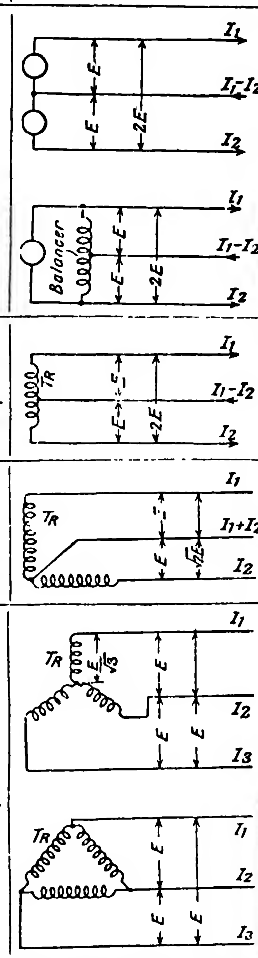
Three-phase transformers are described more fully under the heading Transformer. *See* Mesh Connexion ; Star Connexion.

THREE-PIN PLUG. *See* Plug.

THREE-POLE SWITCH. Also known as a Triple-Pole Switch. In a three-phase circuit, it is usually desirable that the three phases shall be switched on or off simultaneously. For this purpose three single-pole switches, linked together by a common handle or coupled in some other way to break the three phases in unison, are employed. *See* Circuit Breaker ; Switch, *etc.*

THREE-WIRE SYSTEM. Three-wire systems may be D.C., single-phase A.C., two-phase A.C., or three-phase A.C. They are shown diagrammatically. In the first three cases the third conductor is the neutral conductor of the system, and it is usually earthed for reasons explained elsewhere.

Under normal circuit conditions the voltage of each line conductor above or below earth is 50 per cent. of the voltage across the outers, except for case (3),



System	Diagram	Relative Section of Neutral	Relative Total Weights
I		0·5	0·366
D.C.		0·5	0·366
II A.C. single-phase		0·5	0·366
III A.C. two-phase		1·41	1·0
IV A.C. three-phase		—	0·88
		—	0·88

THREE-WIRE SYSTEM Four varieties of the system. Column 4 is for same percentage loss on conductors at same voltages.

where it is 70·7 per cent. With such systems of supply loads can be connected from each line wire to neutral and also across lines. In the fourth case, all three conductors are line conductors, and under normal circuit conditions the voltage of each above or below earth is 58 per cent. of the line voltage.

The relationships between the four systems are shown in the diagram. They may all be applied to underground or overhead constructions for both power and lighting supplies. D.C. three-wire systems are almost obsolete, and existing networks have mostly been converted to three-wire

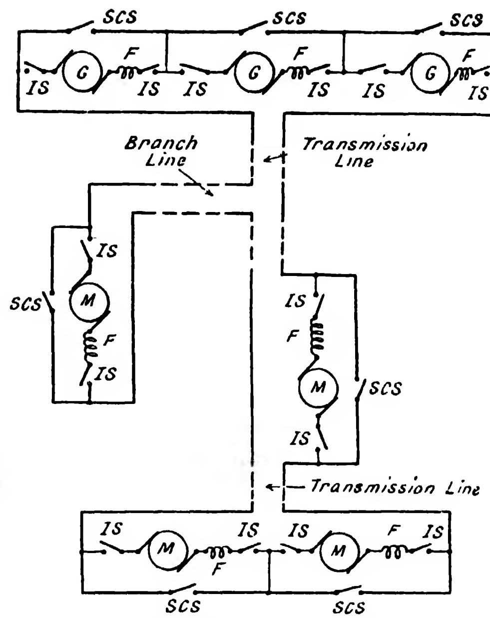
single-phase working. Three-wire, three-phase systems are confined practically to bulk H.T. transmission and distribution, as the most popular system for L.T. distribution is the three-phase, four-wire system (*q.v.*). *See* Distribution.

THROW-OVER SWITCH. A switch, a characteristic of which is that contact is effected by means of a movable arm, which, when thrown over or moved through approximately 180°, makes contact with one or other of two separate contact points. Throw-over switches of small size are frequently used, and can be worked into a circuit in many different ways, examples of which are to be found in many of the circuits illustrated and described in this Encyclopedia. *See* Switch.

THURY REGULATOR. *See* Voltage Regulator.

THURY SYSTEM. The chief difficulty to be overcome in the use of D.C. for long-distance transmission is the generation of sufficiently high voltages, and then the utilization of this high-tension current at the receiving end.

The Thury system, which was developed in France, and is used in a few installations there and elsewhere, attempts this by connecting all the generators and all the motors in series, and regulating them so that, while the current in the line is constant, the voltage varies with the load. A typical system is shown diagrammatically above. The generators are series wound, the voltage being regulated by shifting the brushes and simultaneously shunting the field. They have been built for voltages up to 4,000 volts. As any number up to 20 such machines may be connected in series corresponding to a line voltage of 70,000–80,000 volts they must be completely isolated from earth, and are generally mounted on massive foundations of concrete which rest on a lining of impregnated wooden or rubber blocks. The floor all round each machine is heavily insulated with rubber mats so that the machines can be touched without danger to the attendant. An insulated coupling must also be used between the generator and its prime mover. Incidentally, the design of such couplings presents considerable difficulty. Each machine has



THURY SYSTEM. SCS, short-circuiting switch, IS, isolating switch; G, generator; M, motor; F, field coil.

a short-circuiting switch (SCS) and two isolating switches (IS). It is put out of service by reducing its voltage to zero, closing SCS and opening IS The motors are similar to the generators and are regulated in the same way.

The advantages claimed for the Thury system as compared with A.C. transmission are:

(a) unity power factor,
(b) simple switching arrangements,
(c) stations can be connected in anywhere on the line,
(d) two wires only instead of three,
(e) no trouble with inductive effects and capacity currents,
(f) possibility of effecting repairs while system is in service by earthing one wire at the point where the repairs are to be done.

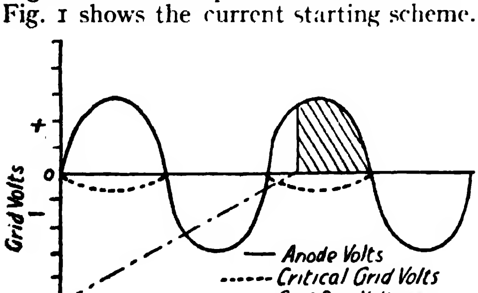
The disadvantages of the system are:

(a) difficulty of insulating the machines, particularly the couplings between the generators and the prime movers,
(b) multiplicity of generator units caused by limitation of D.C. machine design,
(c) the losses are constant and independent of the load, hence poor efficiency on light loads,
(d) the motors have no overload torque (the current and therefore the flux and in consequence the torque are limited),
(e) the regulators are somewhat complicated and must be used on the motors as well as on the generators,
(f) the D.C. machines are liable to damage by lightning surges.

The Marx Rectifier (*q.v.*), recently developed, and also the grid controlled mercury arc rectifier, offer possibilities of high-power D.C. distribution with A.C. generation. *See* Direct Current.

THYRATRON. A coined term used to describe a vacuum valve having an anode, cathode and control grid, into which is introduced inert gas or mercury vapour—designed to act as a grid-controlled arc. The gas provides operating characteristics varying considerably from the three-electrode valve, which it resembles in construction.

Operating Characteristics. When the customary high and low-tension voltages are applied to anode and hot operating cathode respectively and when a critical value of potential is applied to the grid, the electrostatic field at the cathode is varied; ionization (*q.v.*) occurs and a discharge takes place between cathode and anode. In a vacuum tube, the grid controls the plate current, but in the Thyratron this is not always possible, because the ionized gas neutralizes grid potential. The Thyratron grid acts therefore as a starting element and cannot regain control until anode voltage has fallen low enough to permit deionization. The grid can also, with suitable bias, prevent current from starting. These properties are extremely useful, because if A.C. is applied to the anode, the grid can secure a recurring control over cathode-anode tube current once each cycle, when the anode voltage falls through zero. The tube thus acts as a rectifier and current through the tube starts and stops in accordance with the time taken for the grid to pass through its critical value: usually by becoming less negative with respect to the cathode. Fig. 1 shows the current starting scheme.



THYRATRON. Fig. 1. Current flows after critical grid voltage is reached and during the portion of the alternation shown shaded.

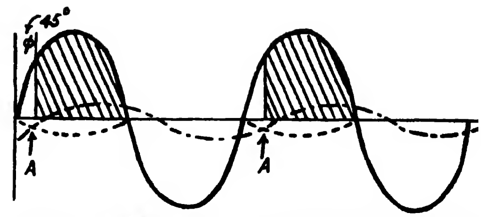


Fig. 2. Code as in Fig. 1. Current starts at A, the intersection of grid volts with critical value for given anode voltage.

A.C. Operation. If A.C. be applied to both anode and cathode, very delicate control of current flow through the tube is possible. This control is effected by varying the phase relationship between plate and grid voltage. Any time period of tube current flow, from almost instantaneous to half-wave rectified impulses,

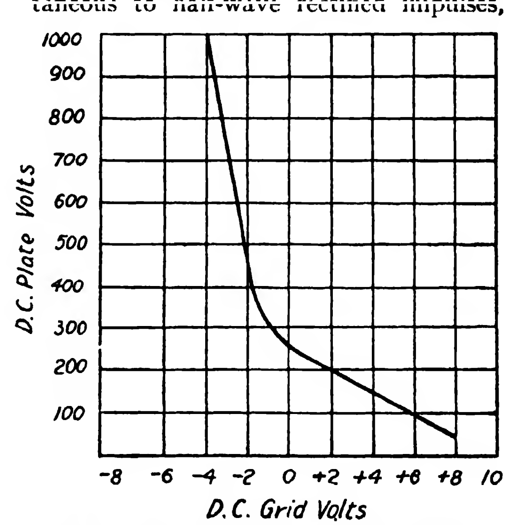
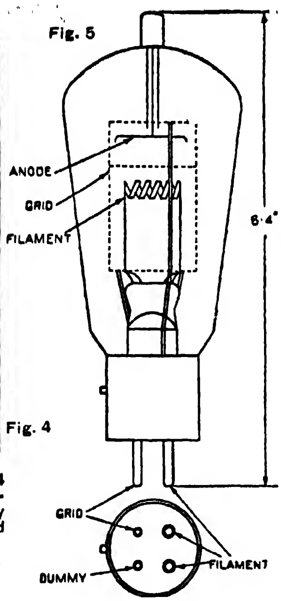


Fig. 3. Starting characteristic for a Thyratron.

can thus be produced. Fig. 2 shows the conditions for 45° phase difference between grid and plate voltage. On the other hand, if a variable potential be applied to the grid, the degree of tube current control takes one of many complicated forms according to the applied voltages and the tube starting characteristics; one is given in Fig. 3. Figs. 4 and 5 show appearance and arrangement of the low-power tube. These tubes can control voltages between 10 and 20,000, with currents of one half to 100 ampères, although instantaneous values may be many times that figure. Thyratrons may also be used to provide A.C. from D.C. by alternating the D.C. supply from one tube to another joined

Fig. 4



THYRATRON. Figs. 4 and 5. Schematic arrangement of a mercury vapour Thyratron, and exterior view.
Courtesy British Thomson-Houston Co., Ltd.

oppositely to the output circuit. Such an arrangement is termed an inverter.

Owing to the neutralization of space charge by ionization, heat-reflecting shields may be placed round the cathode to increase emission efficiency. Consequently, instead of a normal valve efficiency of the order of 100 milliampères per watt, we may have in the Thyratron an efficiency of over one ampère per watt owing to the presence of the gas in the tube.

Applications. Since any desired nature of impulse can be generated in the Thyratron by suitable circuit and potential arrangements, its field of usefulness is wide. It is used extensively in photo-electric relays, where its high response makes it more sensitive than most other relays. Its action, being instantaneous, allows machinery control to be quite positive, whilst on the other hand, so fine can its adjustment be that one is in use in the Cavendish laboratory for counting alpha particles and for other radio-activity studies.

Another use for this remarkable device is for supplying rectified, controlled current to life-testing valve racks. Its self-regulating properties promote both current economy and circuit safety. Thyratron control panels are also used in photo-electric lithographic insetter-printing to produce accurate register in the inset web.

Its use in place of the inefficient dimmer is referred to under Stage Lighting.

Practical Details. Two important points must be borne in mind in operating the Thyratron. Apart from the fact that the cathodes are generally indirectly heated, there is a delay time, from ten seconds to thirty minutes after cathode supply is switched on, before anode potential should be applied. The shortest time is for small directly heated cathodes and the longest for the largest indirectly heated tubes.

The second point relates to arcing back. This is well known in all forms of mercury vapour rectifiers—of which the Thyratron is a type—and is caused by applying voltages to the anode higher or much lower than the rated values. The phenomenon is dependent upon tube temperature. Rated inverse voltages reach as high as 20,000 volts, but a normal value is 1,000 volts, and operating time is from 100 to 1,000 micro-seconds. *See* Hot Cathode; Ionization; Mercury Arc Rectifier; Rectifier; Valve.

THYRITE ARRESTER. *See* Surge Arrester.

TIME CONSTANT. In the article on charging current (*q.v.*) the formula for the decay of current in charging a condenser is given as

$$i = \frac{E}{R}\Sigma^{\frac{-t}{CR}}$$

where i is the current at an instant t seconds after switch is closed,
C is the capacity of the condenser, R the resistance in series,
and Σ a constant equal to 2·7183.

Similarly the formula for the growth of current in an inductive circuit under a steady E.M.F. is

$$i = \frac{E}{R}\Sigma^{\frac{-Rt}{L}}$$

where L is the inductance in the circuit.

The quantities $\frac{L}{R}$ and CR are known as the time constants of their respective circuits, being in the one case the time in which a current will rise from zero to 0·632 $(\Sigma - 1)$ of its final value, and in the other case the time in which the current will fall to $\frac{1}{2 \cdot 7183}$ or $\frac{1}{\Sigma}$ of its final value.

TIME LAG AND TIME-LIMIT RELAYS. Experience has shown that only in

exceptional cases is it desirable that the action of a protective device should be instantaneous. Often the abnormal disturbance guarded against is only of short duration, and sometimes even a fault may be burnt out fairly harmlessly in a few seconds if the supply be maintained. It is therefore desirable that the time taken by the protective device to operate should depend upon the seriousness and dangerous character of the fault.

This condition is to some extent satisfied by an ordinary fuse, which will blow at once on a very heavy overload, but will take some time to break circuit if the current be only a little above the limit. In other words, the greater the danger the shorter is the time of action; hence the term "inverse time" as applied to apparatus having this property. Special fuses are constructed so as to make the time element more definite, but relays with definite mechanical adjustments are preferred in which the minimum current for which the relay is set to act will cause the relay to operate in a definite time, which will become shorter as this minimum current is exceeded.

In modern practice it is becoming increasingly common on large systems to employ relays operating at definite time limits independent of the amount of overload. The maximum time setting allowed is determined by local conditions and the limits are graduated so that the breakers near the fault have time to trip whilst those near the power station remain closed, thereby preserving continuity of supply save on the faulty section itself. The various types of relays employed are discussed under the heading Relays (*q.v.*). *See also* Dash-Pot; Fuse; Protective Devices; Switchgear, *etc.*

TIME SWITCH. Any switch which automatically opens or closes a circuit at predetermined times of the day or night or at a predetermined period after some manual operation.

The simplest form of time switch consists of a contact which is made manually and which by means of a spring return action, retarded by a dash-pot, opens this circuit at a predetermined period afterwards. Such time switches are used largely for the control of lights on staircases common to the tenants of a number of flats on different floors, so that the tenant entering can switch on at the bottom and have the staircase lighted for say two minutes.

Another and rather elementary type of time switch relies on an ordinary alarm clock, which, at a fixed time, operates the gong clapper. In such cases the gong is removed and the gong clapper through an appropriate mechanical connexion operates the dolly of an ordinary tumbler switch, either to switch it on or to switch it off.

In the more elaborate types the clock mechanism is still present, and at a predetermined time a trigger movement is designed to release a contact or contacts

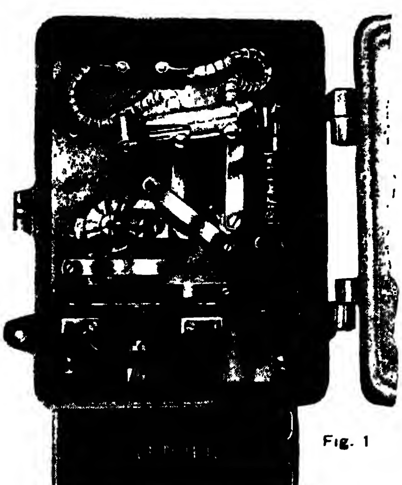


Fig. 1

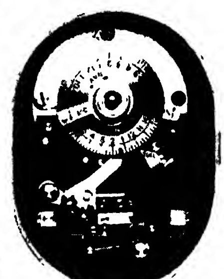


Fig 2

Fig. 3

TIME SWITCH Fig. 1. A staircase switch for use up to 250 volts, 5 amps. Fig 2. A 15-day clock switch used for street lighting. Fig 3. A 40-day switch for shop-window lighting.

Courtesy Venner Time Switches, Ltd.

Fig. 4

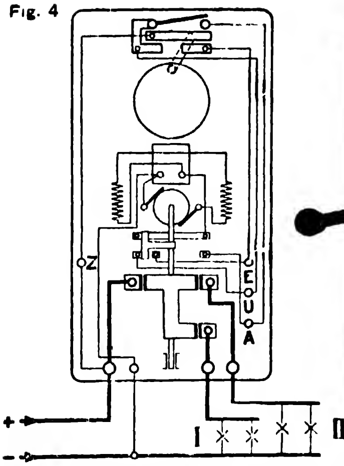
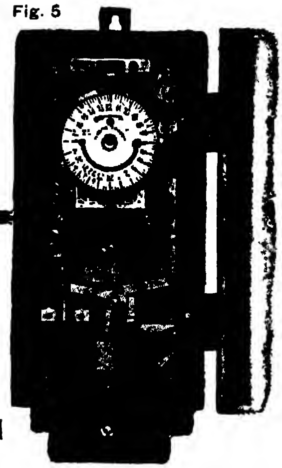


Fig. 5



TIME SWITCH. Figs. 4 and 5. Schematic lay-out and assembled view of automatic staircase switch with electric wind.
Courtesy Nathan & Allen, Ltd

larger types to control even higher currents, but when the control of really heavy currents is required, it is often more convenient to employ some system of remote control such as a contactor (*q.v.*) by which a comparatively small operating current handled by a time switch controls a larger current operating the necessary apparatus. *See* Switch.

and make or break the circuit. By a series of triggers set to operate at given times this making and breaking of the circuit can be repeated almost indefinitely within the limits set by the operating capacity of the clockwork.

An appropriate design of dial and trigger movement in the case of still more elaborate time switches gives an opportunity for setting the switch so that while it operates normally at certain predetermined times, it cuts out altogether during Sunday or any given day in the week.

Time switches of this sort are in common use for shop-window lighting and occasions where the retention of a workman to switch on or off would be too costly, or where it would be impossible for one man to be present at a number of points at the same time. It is particularly in the case of shop-window lighting that a time switch which is co-related with the days of the week in addition to the hours of the day become invaluable.

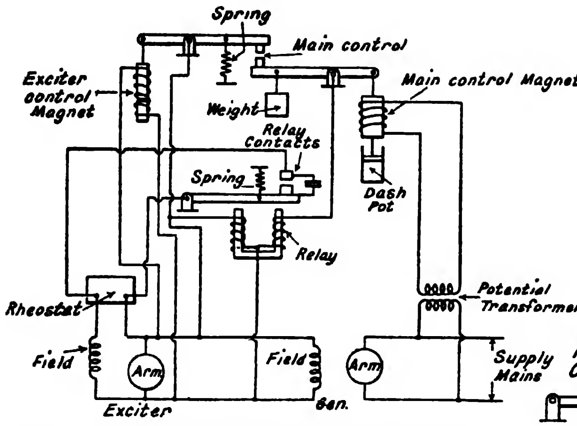
Time switches are also made which alter daily the time of operation according to a predetermined schedule. Such equipment may be used for any lighting control, in which the progress of the calendar requires an earlier or later operation each day. Again, switches incorporating a photoelectric cell may be applied to the automatic switching on and off of lights as daylight disappears and reappears.

Time switches can be made conveniently to control currents up to 50 ampères, and

TIRRELL REGULATOR. The Tirrell automatic regulator is used for the control of the terminal voltage of A.C. and D.C. rotating machines and can be applied to self-excited and separately excited dynamos and generators. It is of the vibrating contact type, and the two applications are shown diagrammatically in Figs. 1 and 2.

In Fig. 1 the control-magnet winding is connected across the supply lines, and when the voltage increases, the magnet core is pulled down and the main contacts, which normally are closed, are thus opened. The relay is wound differentially, one half of the winding being connected across the supply lines and the other half being similarly connected but through the main contacts. Both halves of the relay winding are energized when the main contacts close, and the relay contacts then close and short-circuit the shunt-field rheostat. If the voltage falls the main contacts close, the relay is demagnetized and the relay contacts close and short-circuit the rheostat. The field current then rises until the machine voltage reaches a value a little in excess of the required steady value, when the main contacts open and the short circuit across the field rheostat is removed. The voltage then falls, and upon reaching a value a little below the steady required value, the main contacts open and the cycle of operation is repeated as outlined above. The variation of voltage above and below the required mean is very rapid and usually does not exceed one half of one per cent.

Fig. 2 is similar and has an additional exciter control magnet. If the supply voltage falls, the main contact arm rotates clockwise and closes the main



TIRRELL REGULATOR. Fig. 1. Connexions for separately excited D.C. dynamo.

contacts, which results in short-circuiting the exciter-field rheostat and increasing the supply voltage. This reacts to bring the main contact arm back to its former position. The exciter voltage then increases a little beyond the required value and the main contacts again open, after which the cycle of operation is the same as in the case of the regulator described for Fig. 1. The main contacts constantly vibrate, thus keeping constant the voltage applied to the generator field. *See* Exciter; Field Regulator; Voltage Regulator.

TOASTER, ELECTRIC. The common form of domestic toaster has a mica-wound element arranged vertically, heat being radiated from both sides. This permits one side of each of two pieces of bread being toasted simultaneously. Commonly, means are provided whereby the slices can be reversed by merely pressing a knob, without their having to be touched. This form of toaster is loaded 500–600 watts, the consumption thus being about ½ unit an hour. It takes about three minutes to toast two slices, so that the cost of electricity used in normal every day service is very slight.

Other forms of domestic toasters are the box type and the horizontal element pattern. The former has two vertically arranged elements, flanking the slice of bread, both sides being toasted simultaneously. The horizontal pattern toaster has an open grill-type element, and the bread to be toasted is placed on a grid tray underneath; other small operations, additiona l to toasting, can be carried out on this type.

For restaurant, hotel and commercial catering requirements various multiple toasters are available, in loadings up to several kilowatts. A combined grill and toaster is commonly used. The most complete form of electric toaster is the automatic machine, which not only toasts a number of slices of bread simultaneously, but lifts them out automatically and switches off when the toast is ready.

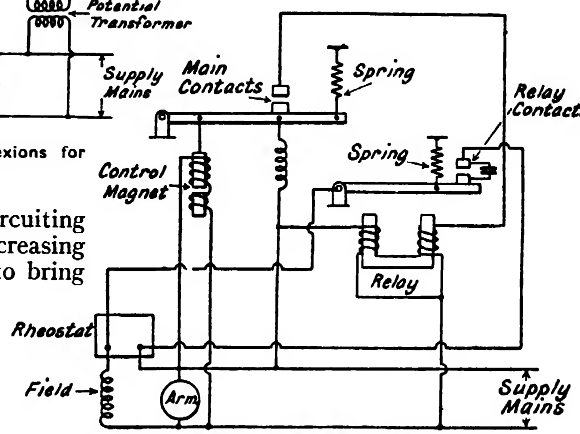
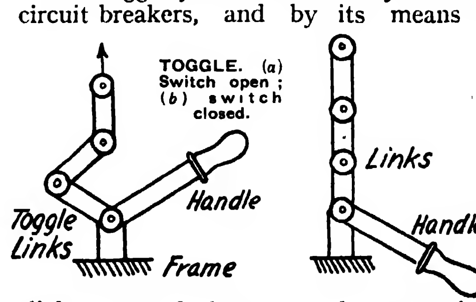


Fig. 2. Connexions for self-excited single-phase alternator.

TOGGLE. A system of linkage which enables pressure to be transmitted at right angles is termed a toggle. A toggle joint is formed when a pair of rods or plates are hinged together by a knee-joint.

The toggle joint is extensively used in circuit breakers, and by its means a slight manual force on the operating handle results in a pressure of some 300 lb. per sq. in. between the contact surfaces.



TOGGLE. (*a*) Switch open; (*b*) switch closed.

The toggle mechanism in essentials is merely an extension of the principle of the lever. If two bars are pivoted in the same straight line with equal and opposite forces at their respective ends no motion results whilst the bars are in alinement. The only force holding them in alinement, however, is the friction of the hinge, and once this has been overcome the forces at the ends tend to increase the out-of-alinement motion more and more. A small force, therefore, will be sufficient to operate a switch mechanism with one compression link in the form of a toggle.

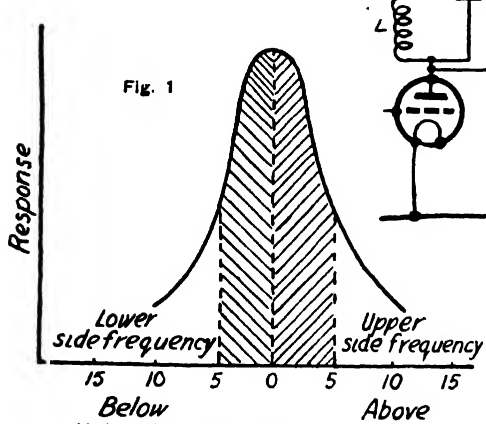
In practice a straight line toggle would be too unstable, and the diagram shows the usual construction adopted. Since a considerable movement of the centre of the toggle results in only a small movement at the ends, any force applied at the centre is multiplied in effect at the ends. When the switch is out and the toggle links at right angles, little power is required to start closing the switch as the force is applied at the centre of the toggle. When the switch is in, the toggle is nearly straight, resulting in a considerable contact pressure. *See* Circuit Breaker.

TONE CONTROL AND CORRECTION. In radio receiving circuits there are various sources of frequency distortion, which is characterized by notes of different frequencies being reproduced at incorrect relative strengths. Tone correction refers to the introduction of special filters in the audio-frequency circuits to compensate as far as possible for such effects and to bring the overall frequency response of the receiver to something approaching uniformity. When the degree of tone correction is made variable and adjustable it is referred to as tone control.

The most serious source of frequency distortion arises in the tuned radio-frequency circuits and is most pronounced with highly selective circuits not of the band-pass type (*see* Selectivity *and* Side Bands). Greatest response occurs at the carrier frequency and falls off rapidly on either side, with the result that the higher note frequencies represented in the side bands are considerably attenuated, the effect being clearly indicated in Fig. 1. The use of band-pass tuning is in itself a method of tone-correction as it passes the side frequencies to a much greater extent for a given degree of selectivity.

Fortunately, the shape of the resonance curve of a tuned circuit is of a nature which renders almost complete compensation possible. The method of tone correction is to include in the audio-frequency circuits, preferably the detector anode circuit, a simple filter which passes high note frequency variations to a greater extent than low ones. Such an arrangement is shown in Fig. 2 where L, C and R_1 form the tone-correcting circuit. By a suitable choice of values the overall response can be made fairly constant over the entire acoustic range.

The action is indicated by the curves of Fig. 3, where A shows the falling off of high notes due to the resonance curve, B is the response curve of the tone corrector circuit, and C is the overall response. By making R_1 and C variable, different degrees of compensation can be obtained to meet different requirements. For instance, reducing R_1 increases the treble response, and varying C alters the range over which correction is obtained. This method makes possible a high degree of selectivity without loss of high notes, and the system has been widely used to this end.



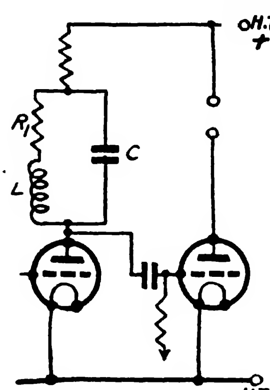


Fig. 2

TONE CONTROL. Fig. 1. Resonance curve showing how the higher notes are reduced ; shaded areas are side bands. Fig. 2. A correcting circuit giving compensation for attenuation of high notes.

TONE CONTROL. Fig. 3. A, response without correction; B, characteristic of tone corrector; C, corrected overall response for Fig. 2. Fig. 4. Tone-compensated volume control.

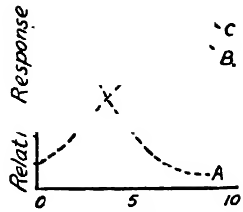


Fig.3

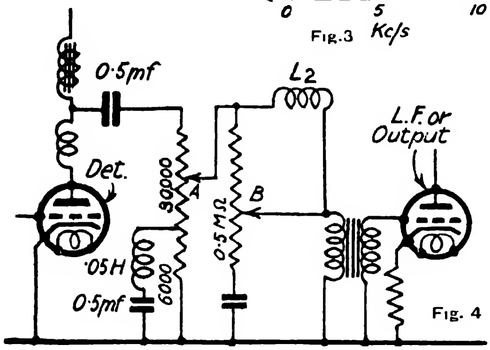


Fig. 4

Tone-compensated Volume Control. It is well known that the ear is more sensitive to sounds in the middle register than at either end of the acoustic frequency scale, and that when the volume is progressively decreased the lowest and highest notes become inaudible first. This effect is compensated for in high-class receivers by incorporating a tone-correcting circuit so as to be automatically adjusted with the volume control, giving a true balance at all volumes.

A practical circuit arrangement is given in Fig. 4. Besides the tone-compensated volume control A, an additional control, B, enables the relative bass and treble response to be adjusted to suit the particular matter being received. When B is set to give the best quality, this quality is maintained for all settings of the volume control.

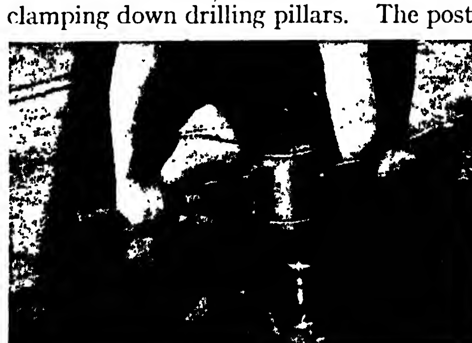
It should be borne in mind that the inclusion of condensers and coils somewhat impairs the response to transients. *See* Distortion; Receiver.

TOOLS, PORTABLE ELECTRIC. In shipyards, heavy engineering works, and locomotive shops where it is difficult to take the work to stationary tools, portable electric tools are essential, and in engineering works and repair shops they save power and time, enabling many processes to be performed out of the usual sequence of operations. Electric drills, reamers, tappers, bolt and screw drivers, nut runners, tube expanders, grinders, sanders, polishing and buffing machines, etc., blowers, and filing machines are all obtainable in portable form.

Universal motors for use on D.C. or single-phase A.C. (25–60 cycles) supplies are generally fitted and will withstand heavy overloads; the gearing dimensions are small, and high-speed armatures running on ball bearings allow the best possible tool speed to be chosen. The tool is conveniently controlled from quick make-and-break push-button or twist grip switches embodied in the handle. Though three-core flexible cable and a visible earthing screw should be fitted (to comply with Home Office regulations), the use of portable tools on high voltages is not recommended and is specially inadvisable on steel constructional work.

Drills. Portable electric drills are available in capacities ranging from $\frac{1}{8}$ in. to $2\frac{1}{2}$ in. holes in mild steel (equivalent to $\frac{1}{4}$ in. and 5 in. in wood); a standard duty drill for $\frac{1}{4}$ in. holes runs at 1,200–1,800 r.p.m., with a current consumption of 170 watts and weighs only 7 lb. High-speed twist drills must be used, and a chuck or a Morse taper socket is provided. Pistol grips are fitted on the small sizes, and breast plates, mounted on the top plate of the motor, or feed screws on the larger sizes. The motor is usually housed in a casing of cast steel or aluminium. Spring-well oil cup lubricators ensure adequate lubrication of the ball bearings on the armature shaft and the ball thrust washers on the drill spindle.

The use of magnetic drill posts (where D.C. is available) avoids the need for clamping down drilling pillars. The posts



TOOLS, PORTABLE. Fig 1. A woodborer drilling holes in railway sleepers.
Courtesy Consolidated Pneumatic Tool Co., Ltd.

are placed on the steel or ironwork to be drilled, and when the current is switched on the equipment is held magnetically against its own weight and the feed pressure of the drill; single or double posts are required according to the size of the holes, the current consumption ranging from 370 to 880 watts. For holes up to 2 in. in thin mild steel or cast iron tanks an electro-magnetic holding-on drilling machine can be slung from a crane; the total current consumption is 1,250 watts, and a $\frac{1}{4}$ in. starting hole is necessary.

Electric screwdrivers and nut runners (differing only in the type of bit) run at lower speeds and are fitted with a positive clutch to release the drive when the nut or screw has been driven home; reamers and tappers have capacities somewhat smaller than those of the corresponding drills and are provided with reversing gear.

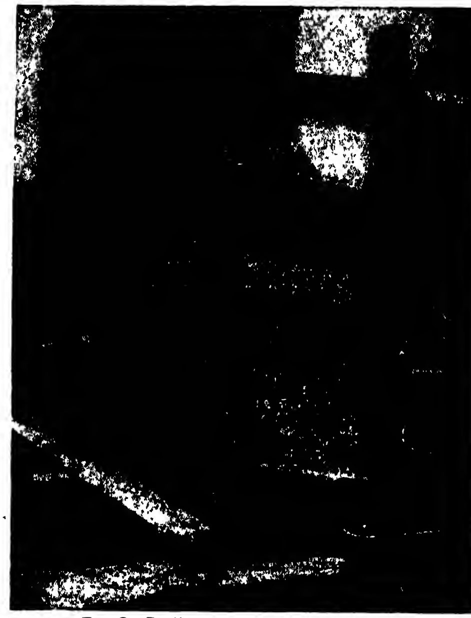
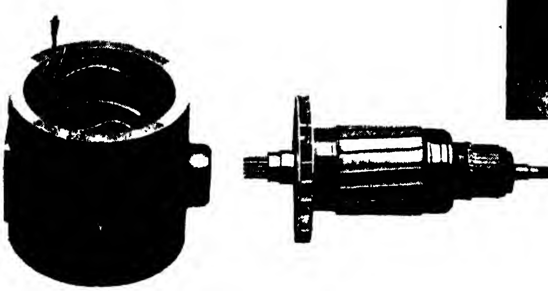


Fig. 3. Drilling holes in headstock of a railway carriage frame.
Consolidated Pneumatic Tool Co., Ltd.



TOOLS, PORTABLE. Fig. 2. The armature and field casting of a portable heavy duty drill.
olidated Pneumatic Tool Co., Ltd.

Grinders. Portable electric grinders can only be used on D.C. because of the tendency of universal motors to race at no load, producing a centrifugal force that might break the grinding wheel. The motor should be totally enclosed to keep out grit. Two useful sizes have grinding wheels of 4 and 6 in. diameter and weigh 11 and 30 lb. respectively; the corresponding no-load speeds are 5,000 and 4,000 r.p.m. and the current consumptions 100 and 500 watts. Hand grinders, for surface grinding, can be provided with an adjustable carriage to regulate the depth of cut.

Grinders for use on benches or the tool posts of lathes can be equipped with a squirrel-cage motor for an A.C. supply. A taper spindle to take a polishing mop instead of the grinding wheel, or a double spindle extension for both grinding and polishing, can be fitted.

For dealing with awkward corners and curved surfaces, flexible shaft grinding equipments should be used, the motor

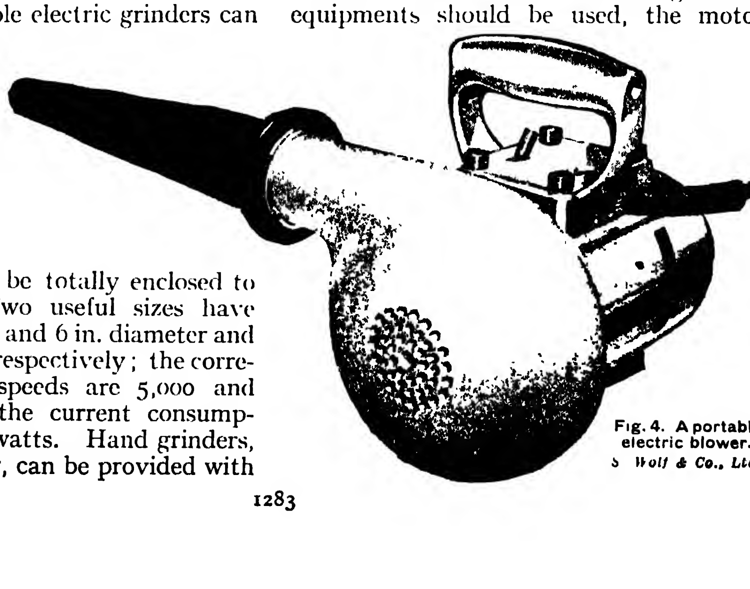


Fig. 4. A portable electric blower.
S. Wolf & Co., Ltd.

(D.C. or A.C.) being totally enclosed for outdoor work.

Hand saws enable wood, fibre, lead, etc., to be cut very rapidly; some sort of automatic guard is desirable to avoid danger from the exposed blade.

Blowers. Portable electric blowers enable dust to be removed from the windings of electrical machinery and other equipment in garages, factories, builders' yards, shipyards, metal works, and wireless and railway shops. The weight (with 6 ft. of armoured rubber tubing) is only about 26 lb., so that the blower itself can be held by the operator; otherwise it may be rested on the ground or bench, and the tubing nozzle directed on to the work. With a universal motor having a current consumption of about 800 watts, a volume of 130 cu. ft. of air per minute is discharged at a pressure of about 22 ins. of water. A smaller type giving an air pressure of about 12 ins. of water and weighing only 15 lb. is light enough to hold close to the work, no flexible tubing being necessary. If it is important to avoid a dust-laden atmosphere, the flexible tubing can be changed over to the air inlet and the outlet fitted with a bag for collecting dust, thus converting the blower into a suction cleaner. *See* Machine Tools.

TOOTH. The punching out of slots to carry the winding on the laminated core of an armature leaves a series of projections which play an important part in reducing the reluctance of the magnetic circuit. In calculating the ampère-turns required to generate a given E.M.F. in a machine the designer has to calculate the magnetic flux and iron losses in each part of the magnetic circuit. The determination of the tooth density and the corresponding magneto-motive force is based upon a series of empirical approximations which are entirely beyond the scope of this work.

The shape of the teeth obviously depends on the shape of the slots cut out of the core laminations, various types of which are illustrated on page 719. These in turn depend on the amount of insulation necessary and the space factor (*q.v.*). For high-speed alternators employing segmental laminations, the latter are provided with lugs and can be dovetailed to the arms of the armature spider, to secure them against the action of centrifugal force. On smooth core and tunnelled armatures no teeth are provided, of course, and the magnetic leakage effects are considerably greater. *See* Laminations; Slot; Smooth Core Armature; Tunnel Winding, *etc.*

TOROID. When a solenoid is bent up into the form of a closed ring it is known as a toroid. Such toroidal coils are sometimes employed in telephone transformers and repeating coils. Owing to their construction they have no magnetic poles. The formula for the flux in a solenoid still holds, namely: $H \; \frac{4\pi NI}{10l}$, where H is the strength of the field, N the number of coil turns, l the length of the solenoid, and I the current flowing in the coil. *See* Flux and Flux Density; Solenoid.

TORQUE. The tendency to turn any body about an axis, *i.e.* the twisting moment or product of the force exerted on the body and the perpendicular distance of the line of action of the force from the axis. The torque exerted by a force of one pound at a radius of one foot is called the turning moment unit in the foot-pound system, whilst in the C.G.S. system a torque of one gramme centimetre is exerted by one gramme at a radius of one centimetre. Many instances occur in electrical and magnetic work; for example, there is a torque exerted on a magnetic needle placed in the earth's field, tending to set it in the direction of the magnetic meridian (*see* Magnetic Couple).

Motor Torque. The fundamental principle at the root of the operation of all motors is to be found in the magnetic torque exerted on a current-carrying conductor situated in a magnetic field. The magnitude of the total force on the conductor depends upon three factors: (*a*) the length of the conductor lying at right angles to the field and to the direction of the force; (*b*) the current strength; (*c*) the flux density. From this, since the force is proportional to each of the three factors given above,

$$F = B \times i \times l \text{ dynes}$$

where F is the force, i the current strength, B the flux density, and l the length of conductor perpendicular to flux and force.

The torque will then equal

$F \times \frac{d}{2}$ where d is the diameter of the armature lying in the air-gap.

If the armature consists of N turns then the torque

$$J = F \times \frac{d}{2} = \frac{B\,i\,l\,N\,d}{2}$$

The horse-power output is the product of the torque and the angular velocity and therefore if R is revolutions per minute,

$$\text{Power output} = \frac{B\,i\,l\,N\,d}{2} \times \frac{2\,\pi\,R}{60}$$

$$\text{dyne-centimetres per second} = \frac{B\,i\,l\,N\,d\,\pi\,R}{60 \times 10^8} \text{ watts.}$$

The output from the conductors also equals eI watts where e is the E.M.F. applied and I the current in amps. taken by the motor, and from these equations the torque and power output can easily be calculated. Since all the quantities save two in the former equation are constant, we can state that the torque is proportional to the armature current and the magnetic flux per pole.

Starting Torque. The force on the conductors accelerates the armature which then generates a back E.M.F. proportional to the speed. Hence as the speed rises the increased back E.M.F. reduces the current and so also the driving torque. Consequently the speed will rise to such a value that the driving torque exactly equals the resisting or load torque.

Load Torque. The relation between speed and torque of a given motor determines the class of work for which it is most suitable. The mechanical characteristics of motors under various conditions of supply are given in the diagrams on pages 859 and 860. The shape of the torque-speed curve for the series motor is instructive, and shows the great suitability of that type of motor for starting under heavy load as in crane work and traction. These speed-torque curves are obtained by means of a Prony brake (*q.v.*) fastened to the pulley of the motor, a series of readings of speed and torque being taken and the curves plotted. The brake horse-power (*q.v.*) is the product of the speed, torque, and the constant

$$\frac{2\,\pi}{33000}, \text{ equal to } 0{\cdot}0001902.$$

Pull-Out Torque. The characteristics of the three-phase induction motor are described under Slip (*q.v.*). The value of the overload torque at which the induction motor falls out of synchronism is termed the pull-out torque. This is the maximum torque the motor will give, and when testing for this value, the voltage should be held constant at the normal rated voltage of the motor under test.

Synchronizing Torque. When two alternators are to be synchronized for parallel operation (*q.v.*), the paralleling switch is closed at a moment when the speed, voltage and phase relationships are practically identical. Should the voltages be unequal or out of phase to a slight extent, one alternator will be driven as a motor supplied with power from the other and a synchronizing torque will be set up and pull the two into step. *See* Synchronizing.

Instrument Torque. If a light rectangular coil is freely pivoted in an annular air gap with a uniform magnetic field, when a current is passed through the coil, a torque will be exerted on it exactly proportional to that current. If n is the number of turns on the coil, W the mean width, H the field strength in the air gap, l the effective length of coil sides, I the current in ampères, then the

$$\text{Torque} = \frac{H\,I\,l\,n\,W}{10} \text{ dyne-centimetres}$$

The movement of the coil is controlled by hair springs, and since the deflection of a spring is proportional to the torque, the deflection of the pointer on the coil will be exactly proportional to the current. *See* Dynamometer ; Meters ; Prony Brake.

TORSION BALANCE. A laboratory instrument originated by Michell and improved by Coulomb, employed in investigations of the magnetic effects between two bodies. For example, the law of inverse squares, stating that the force exerted by one magnetic pole on another in its neighbourhood is inversely proportional to the square of the distance between the poles, may be proved by means of this instrument. The underlying principle will be understood by reference to the torsion galvanometer, which in essentials is a modification of the original torsion balance. *See* Electrometer.

TORSION GALVANOMETER. A sensitive form of galvanometer used chiefly in laboratory tests. A magnet, or a coil

consisting of many turns of fine wire, is suspended freely in a strong magnetic field, *i.e.* between poles of a permanent magnet, by means of a fine phosphor-bronze strip. This strip is attached at its upper end to a torsion head enabling the zero of the instrument to be adjusted. The phosphor-bronze strip exerts a controlling couple on the coil and serves as the lead-in for the current to the wire. A small silver fibre attached below the coil serves as the negative lead. The movement of the coil may be observed by the deflection of a beam of light reflected from a mirror suspended over the coil as in the Einthoven galvanometer (*q.v.*). The deflections of the light beam are practically proportional to the current and the scale can be calibrated in current units. *See* Galvanometer.

TOUGH RUBBER WIRING. This class of insulation was first introduced under the name of "Cab Tire" by the St. Helen's Cable and Rubber Co., and originally devised for flexibles it is also widely used for ordinary wiring purposes, The tough rubber mixture which is applied as an outer protector over the usual V.I.R. insulation is very robust and resilient. Practically all the cable makers now issue cables with tough rubber sheathing. The wiring is very easy to instal as the insulated covering eliminates the need for continuous bonding. When earthing on the system is desired the cable is obtainable with an additional copper core for this purpose.

Tough rubber wiring may be run on the surface or buried in plaster. It is impervious to damp, but when much moisture is present the cable should be run on china cleats to permit a free passage of air all around. Tough rubber cables are now obtainable with a white sheathing for surface work in houses, to tone with the light-coloured walls and ceilings.

Care should be taken to avoid surface wiring in positions subject to the action of direct sunlight, or places where there is excessive vibration. In such situations the sheathing is liable to crack in time. Bakelite junction boxes are used for normal work, but if conditions are very severe, as in laundries, public baths, stables and the like, then it is necessary to employ the special sealable china fitments supplied for such purposes. In some districts tough rubber wiring has had great popularity in Council houses. *See* Cable; Wiring.

TRACTION, ELECTRIC: PRINCIPLES AND EQUIPMENT

By A. T. Dover, M.I.E.E., A.Amer.I E.E., Author of "Electric Traction"

This comprehensive outline includes the application of electric power to tramways, railways, road vehicles, mines and canals. A general review of the subject is given first, followed by an examination of the general principles of electric traction and notes on the equipment of railways and tramways. Details and special or related aspects of the subject are covered under other headings, as Frequency Changer, Motors, Induction Motors, Series Motors, Rectifiers (for D.C. supplies), Sub-stations, Transformers, etc. See Trolley-bus for that vehicle.

The subject of electric traction includes the application of electric power to tramways, railways, road vehicles (*i.e.* trolley-buses, commercial electric vehicles and trucks for short-distance goods transport), mines and canals (in cases where electric haulage is necessary). After a general review of the subject this section is mainly concerned with the general principles and equipment for tramways and railways.

ELECTRIC TRAMWAYS

Electric traction for passenger transport on street tramways has been in operation since about 1888. The cars run on rails which are usually laid with the tread flush with the road surface in order that the roadway may be used by other vehicles. Power for propulsion is obtained from a single overhead conductor, the track rails forming the return conductor. In special cases (*e.g.* near magnetic observatories), where earth currents are not permissible, two overhead conductors are employed, and in cases where overhead construction is not permissible the conductors, from which the cars obtain power, are located in a slotted underground conduit in the centre of the track rails. This (underground conduit) construction is very costly, and in this

country has only been employed in certain parts of London.

Modern double-deck tramcars for British conditions can accommodate about 80 seated passengers. Such cars weigh about 14 tons unloaded and are equipped with two 50-h.p. motors.

Statutory Regulations. All tramways in Great Britain have to comply with stringent statutory regulations which concern the power supply and distribution system, the track, cars and their equipment, and routine tests and records.

The power supply is limited to the direct current system at a voltage (at the cars) not exceeding 550 volts. When the track rails are used as return conductors they must be connected by insulated cables to the negative bus-bar at the power station, which must be earthed by means of two earth plates with a current indicator in the circuit. The negative portion of the distribution system must be designed so that the voltage drop in the track rails under the heaviest service conditions does not exceed 7 volts. The separate lengths of rail, and the rails of a single or double track, must be electrically connected so as to make the track rails, as far as practicable, a continuous and effective electrical conductor.

The overhead conductor, or trolley wire, must be divided into sections, not exceeding one half mile in length, with a switch between every two sections, so that any section can be isolated in emergencies. The span must not exceed 120 ft. and the height above the road surface should normally be 22 ft.

Tramway and Trolley-bus Compared. A trolley-bus (*q.v.*) system has the advantage, over a tramway system, of mobility, and the vehicles can operate in narrow and congested thoroughfares with fewer delays, and consequently at a higher schedule speed, than tramcars. Another advantage of a trolley-bus system is that no expensive track has to be laid and maintained. On the other hand, the maintenance of the chassis and tires of a bus is more costly than that of the corresponding portions of a tramcar ; the energy consumption is greater ; and the vehicle accommodates fewer passengers.

A tramway system is, therefore, better suited for handling very heavy and dense traffic in large cities, as the earning capacity of the expensive track is then fully utilized and a remunerative return for the invested capital is assured. A tramway system is always faced with the relaying of the track at intervals of from 5 to 10 years, or less, according to traffic, in addition to the regular maintenance of the track and road surface, not only between the rails, but also to a width of 15 in. on each side of the track. When the system is working remuneratively the cost of such renewals and maintenance is provided for automatically by annual payments to a reserve or renewal fund. Similar payments allow for the replacement of the cars and equipment when these become obsolete after, say, 20 to 30 years' service.

With some tramways, however, the financial conditions may be such that, when the worn-out or obsolescent stage is reached, the car replacements and track relaying can only be effected by the borrowing of new capital. The interest charges on this capital will still further increase the standing charges and embarrass the financial position of the undertaking.

In such cases it would be preferable to replace the tramcars by trolley-buses, as the cost of relaying the track would be avoided, although the cost of making good the road surface for vehicular traffic would have to be incurred. Maintenance charges for track and road surface would also be avoided. The total capital expenditure involved by replacing the tramway system with a trolley-bus system may, therefore, be considerably less than that of rehabilitating the tramway system, while the saving in interest charges may more than balance the increased maintenance charges on the trolley-buses (*see further under* Trolley-Bus).

ELECTRIC RAILWAYS

Suburban Lines. Electric traction on suburban lines becomes essential when the traffic density is high, as steam traction is incapable of handling such traffic economically owing to the resulting low schedule speed and the delays at terminal stations. With keen competition from fast road transport systems, operating over parallel routes, the railway with steam operation will often be unable to retain its patrons.

Electric traction is also essential for operation in underground and tube railways and in long tunnels. It is also essential when smoke and steam are prohibited at terminal stations in large cities (*e.g.* New York).

Electric traction on suburban lines not only gives a higher schedule speed, compared with steam traction, but also a higher utilization of the tracks, thereby enabling a greater number of trains per hour to be run over a given track. Moreover, with motor-coach trains (as now universally used for suburban services) the length of train can be increased to the limit imposed by the length of the platforms, and the schedule speed will not be affected thereby.

Electric traction has the following advantages for suburban lines: (1) High schedule speed with frequent stops is possible because of the large supply of energy available from the power supply system, combined with the large short-time overload capacity of the electrical equipment, and the large tractive effort which can be obtained from the driving wheels of a motor-coach train without excessive axle loadings.

(2) A short lay-over time only is necessary for the trains at terminal stations, owing to the few signal movements required to admit and release a motor-coach train from a terminus. Moreover, no time is required for coaling, watering, or cleaning fires, as with steam traction.

(3) Improved train service, which, due to the high utilization of the track, is limited only by the signalling capabilities of the line.

(4) High traffic utilization of the trains owing to absence of coaling, watering, cleaning of fires, cleaning of boilers, renewal of fire bars, etc.

(5) Low costs of maintenance and renewal charges.

(7) Smaller personnel necessary owing to the fewer number of trains in service and the absence of a fireman on each train.

Main Lines. Electric traction on main lines is necessary in cases when:

(1) high-grade steam coal suitable for locomotives is scarce and expensive, electrical energy being available either from water-power plants or steam-power stations burning low-grade coal; (2) the route crosses mountain ranges with long and steep gradients and/or long tunnels; (3) the operating conditions (*e.g.* absence of smoke, cinders, etc.) are to be improved.

The advantages of electric traction over steam traction for main lines may be summarized as follows: (1) Electric traction is safer and more economical in operation and maintenance than steam traction on lines having steep and long gradients or long tunnels. The greater safety in operation on gradients is due to the employment of electric braking on the locomotive, thereby freeing the brakes on the vehicles and preventing the possibility of loose wheel tires (which is liable to occur, due to overheating, when the ordinary wheel brakes are applied for long periods).

(2) Higher operating speeds are practicable on gradients, due to electric braking and the relatively large power available from the supply system.

(3) Heavier trains can be handled on the gradients, due to electric braking and the easier and smoother control of the electric locomotive compared with the steam locomotive.

(4) The electric locomotive, although slightly more costly initially, than a steam locomotive of corresponding output, costs relatively little to maintain, whereas the maintenance of a steam locomotive is a very considerable item. Moreover, the electric locomotive can be kept in service for long periods and its operation is unaffected by abnormal weather, such as severe cold in winter. Further, the life of an electric locomotive is longer than that of a steam locomotive.

(5) Electric heating of the trains gives greater comfort to the passengers than steam heating, and requires less maintenance than the latter. Moreover, the carriages may be preheated when standing in the stations. Further, the heating system does not become frozen in winter.

(6) No coal wharves, stocked with high-grade steam coal, or water towers (for the coaling and watering of steam locomotives) are necessary; likewise locomotive running sheds or "round houses" are unnecessary.

(7) An electric locomotive is not usually completely incapacitated by a defect in one of the driving motors, as in many cases the defective motor can be cut out of service and the locomotive can proceed on the remaining motors.

Objections to Main-Line Electrification in Great Britain. With the exception of the Southern Railway (which has a large mileage of suburban and main lines—Central Section—working with electric traction) all the railways in this country are apathetic towards main-line, and, in many cases also, suburban-line, electrification, notwithstanding the fact that the Weir Commission on main-line electrification showed that such electrification would be beneficial to the country and that it would ultimately be more economical than the present steam-operated system.

The chief objections to universal electrification of the main lines in this country are apparently (1) the large cost which would be involved, and (2) the existence of a plentiful supply of high-grade steam coal.

It is probable, however, that in the near future considerable improvements may be made in the heat efficiency of electric power plants burning low-grade fuel, in which case electrical energy could be supplied to the railways at such a low price that the reduced operating costs under electrical working would soon pay for the cost of electrification.

Suburban-Line Systems. The direct-current system, at 600 to 700 volts, is universally employed for suburban electrification, as the D.C. series motor (*q.v.*) has the best operating characteristics, the highest efficiency, and the lowest weight—in comparison with other types of motors—for this service. In some cases, however, a higher voltage—1,500 volts—is employed, thus leading to economy in the distribution system and reducing the number of sub-stations.

Main-Line Systems. The D.C. and A.C. (single-phase and three-phase) systems are in extensive use, the total mileage of these systems for the whole world being approximately :

Direct-current	10,000 miles
Alternating-current, single-phase	10,000 „
Alternating-current, three-phase	2,000 „

D.C. System. The direct current system is in use at voltages of 600, 1,500, 2,400 and 3,000 volts, the lowest of which (*i.e.* 600 volts) is employed only for short distances (about 50 miles), when the main line forms an extension of an extensive suburban system, as on the Southern Railway (Central Section). Voltages of 1,500 and 3,000 volts are now standard, the lower voltage being employed for the shorter distances (100 miles) with heavy traffic, and the higher voltage for the longer distances.

Single-Phase A.C. System. This is used extensively for main lines in Europe, the distribution voltage being 15,000 volts and the frequency $16\frac{2}{3}$ cycles per second. In America, however, the distribution voltage is usually 11,000 volts and the frequency is 25 cycles per second.

The low frequency is essential in order that the series type of motor (which is the only type of single-phase motor suitable for traction service) may be used. Hence when energy is purchased from an industrial supply network (on which the frequency is 50 cycles per second) frequency changers (*q.v.*) in addition to transformers must be installed in the sub-stations.

To obviate this disadvantage schemes have been developed for supplying the traction distribution system with single-phase energy at 50 cycles from the industrial supply network, and to convert this energy, by converting plant on each locomotive, into suitable form for the traction motors. In one successful scheme (due to de Kando, and in service on the Hungarian State Railways) single-phase energy, at 16,000 volts 50 cycles, is supplied to all locomotives and is converted by a phase converter on each locomotive to three-phase energy at 50 cycles for use in the three-phase induction-type 1,800-h.p. driving motor.

Three-Phase A.C. System. The three-phase alternating-current system is used extensively on the State Railways in North Italy, on which many long lines, steep gradients and long tunnels occur. The distribution voltage is 3,600 volts, and the frequency is $16\frac{2}{3}$ cycles. The medium voltage of 3,600 volts was chosen to enable the traction motors to be supplied directly from the distribution system, and the low frequency of $16\frac{2}{3}$ cycles enables the low-speed gearless motors (with which the locomotives are equipped) to operate at high power-factor and efficiency.

The electrification of these Italian lines was commenced in the early days of

electric railways, and before the high-voltage direct-current and single-phase systems had been perfected, and the three-phase system was chosen principally because of the facility and effectiveness with which electric regenerative braking (*q.v.*) can be obtained, no additional apparatus being necessary for this purpose.

The chief disadvantage of the three-phase system, compared with the direct-current and single-phase systems, is that two overhead high-voltage conductors are necessary for each track. Overhead construction is therefore complicated, particularly at junctions and cross-overs.

Choice of Main-Line System. This involves the consideration of many factors, particularly the national sources of energy and the national industries of the country concerned. At the present day the high-voltage direct-current system and the single-phase system are each capable of giving satisfactory service, and neither system has such outstanding technical merits as to give it superiority over the other system in all circumstances.

For example, in the D.C. system the motors have a high efficiency and their maintenance cost is low ; but the distribution system is costly (on account of the relatively low voltage) and numerous sub-stations are required.

In the single-phase system the motors are more costly both initially and in maintenance, their efficiency is lower than those for the D.C. system, and an expensive transformer forms a necessary part of the motor equipment ; but the distribution system is very much cheaper than that for the D.C. system on account of the moderately high voltage and the small number of sub-stations.

The three-phase system possesses advantages of its own, particularly when the distribution voltage is so chosen that transformers are unnecessary on the locomotives ; but the complication in the overhead construction is looked upon by the majority of electric-railway engineers as insurmountable, and, in their opinion, entirely outweighs the advantages of the system.

Composite A.C. and A.C.-D.C. Systems. The straight low-frequency single-phase system with series motor equipments is unsuitable when regenerative braking is required on a large scale, owing to the low efficiency and low power factor during braking, and the relatively heavy auxiliary apparatus which is necessary for this purpose.

Hence, when regenerative braking is of prime importance, as on mountain grades, and the advantages of a high-voltage single-phase distribution system are desired, the locomotives are equipped with either phase converters or motor generators (*q.v.*) to convert the single-phase energy into either three-phase or direct-current energy for the traction motors (which are of the direct-current or three-phase induction type as the case may be). Two American railways (*viz.* the Norfolk and Western, and the Great Northern) employ such composite systems.

OTHER FORMS OF TRACTION

Diesel-Flectric Traction. The Diesel engine is a high-compression internal-combustion engine having a high thermal efficiency and working with relatively cheap, heavy oil fuel. A Diesel locomotive, therefore, would possess similar advantages to a steam locomotive, in that it is independent of an external power supply system. But the Diesel engine, in common with all internal-combustion engines, is incapable of developing large torques at low speeds, and change-speed gearing is necessary to adapt the engine characteristics to traction purposes. Such gearing is incapable of giving satisfactory service for high powers, and this difficulty is overcome by employing an electric system for the power transmission.

The Diesel-Electric System. In this system the Diesel engine is coupled to a D.C. generator and operates at approximately constant speed, although in some cases a limited range of engine speed control is employed to obtain an increase of output at the higher train speeds. The D.C. generator supplies the traction motors (which are of the ordinary series-wound type), and starting and speed control of these motors is effected by variation of the voltage of the generator, the latter being separately excited from an auxiliary generator, which is also coupled to the engine. The auxiliary generator also supplies energy for the

auxiliary equipment, lighting equipment, and battery charging; it is also used as a starting motor for the engine, energy being supplied from the storage battery.

Diesel-electric traction is eminently suitable for railways which can obtain adequate and cheap supplies of suitable fuel oil, and where coal and water power are scarce or unavailable. As the Diesel locomotive has no standby losses—such as occur in a steam locomotive—the system is suitable for railways on which the traffic is light and the service is infrequent, as considerable economies can be effected in comparison with steam operation, even when coal is available.

High-power locomotives could be built, when required, for main-line service, but they would be much heavier than a steam or electric locomotive of equal power, and their maintenance would be more costly than that of a steam locomotive of corresponding output. In general, under British main-line conditions, the operating costs (including running, maintenance, renewals, and overhead charges) of Diesel-electric traction would probably be higher than those for steam traction. Moreover, the operation of the railway system would be dependent upon free supply and low cost of the fuel oil.

Storage Battery Traction. This form of traction is only possible when adequate facilities are available for recharging or changing the batteries. At the present time its application is restricted to shunting and works locomotives; commercial delivery vehicles in large towns; platform trucks at large railway stations; underground haulage in mines.

There are a few isolated examples of railway traction with storage batteries, *e.g.* the Great Southern Railways of Ireland (motor-coach operation with Drumm batteries (*q.v.*) on a short suburban line), and the South India Railway—Madras electrification—(electric locomotive operation beyond the electrified sections, by means of batteries carried on tenders, which are coupled to the locomotives at the terminus of the electric section).

Commercial Electric Vehicles. The commercial electric vehicle for town delivery service may, in the near future, be employed in large numbers, particularly if favourable "off-peak" charging tariffs are available. Such vehicles have a number of advantages over petrol-driven and horse-drawn vehicles, and are preferred to petrol-driven vehicles by a number of transport companies, specializing in the transport of food-stuffs, owing to the absence of smell and fumes.

Outstanding features of the electric vehicle, compared with a petrol-driven vehicle, are—the low h.p. rating of the driving motor, the simplicity of control and manœuvring, the impossibility of abuse by excessive speed, the exceptionally low maintenance of the driving motor and control gear.

A modern light delivery van for loads up to 7 cwt. will run about 40 miles on a single charge, and will require about 12 kWh. of energy from the electric supply for the recharging of its batteries.

The battery usually consists of 40 lead-type cells or 60 alkaline-type cells, these numbers being chosen so as to be suitable for charging directly from 110-V mains. The lead battery is the heavier for a given ampère-hour rating, but is the more compact and gives less variation of voltage on discharge.

Electric Traction in Mines. Some of our more progressive collieries are now employing electric traction for underground and surface haulage when the conditions are suitable. In the Harworth Colliery electric traction is also employed underground for the transport of the colliers from the pit shaft to the working face, thereby saving these men half an hour's walk in each direction.

In all cases locomotives are employed, which are propelled by energy derived either from storage batteries carried on the locomotive or from an overhead trolley wire. The former method of operation is used underground, and the latter on the surface, although some large non-fiery American and European mines employ the overhead trolley system both on the surface and underground.

The locomotives for underground service are characterized by (1) the narrow gauge (18 in. to 24 in.), and (2) the low overall height. They have usually two axles, which are either driven by separate motors, or collectively driven from a single motor. On account of the very restricted space available for the motors,

the aggregate rating of a locomotive rarely exceeds 8 h.p.

A typical locomotive weighs about 10 tons and is capable of hauling loads of from 5 to 20 tons on the level at speeds of 6 and 3 m.p.h. respectively. The locomotive is capable of pulling a load of 5 tons up a gradient of 1 in 20, and of exerting a starting pull of 2,000 lb.

Operating Principles: Schedules, Power and Energy

Speed-Time and Distance-Time Curves. These curves show respectively the speed of a vehicle or train at any given instant, and its position, or the distance run, from the start. They have very important uses in connexion with the determination of schedules, and the calculation of the power required for propulsion.

For example, (1) the area enclosed by a speed-time curve for a given time interval represents the distance run by the vehicle or train during this interval, (2) the slope of the curve at any point represents the acceleration or retardation at that instant, an upward (or positive) slope representing acceleration and a downward (or negative slope) representing retardation (sometimes called deceleration).

Hence from a speed-time curve representing the run of, say, an electric train between two stations or stopping points, the average running speed and the schedule speed of the train may be calculated as shown below.

A typical speed-time curve for an electric train working suburban service on level track is shown in the upper portion of Fig. 1, and the corresponding distance-time curve is shown in the lower portion of this figure.

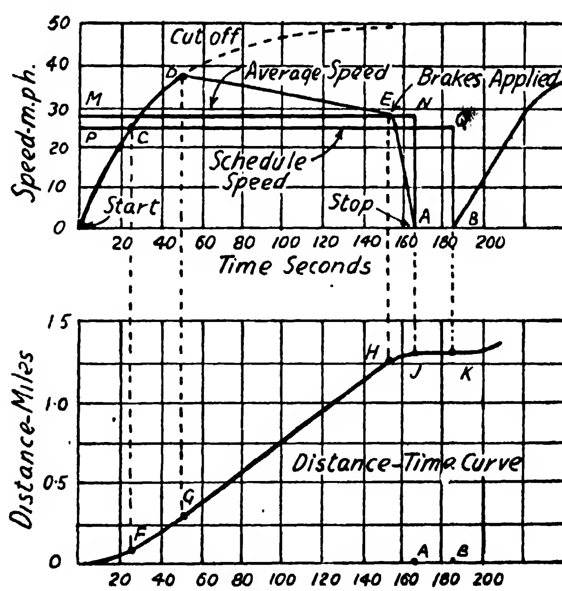
The particular shape of the speed-time curve is typical for suburban operation with D.C. series motor equipments. This curve (Fig. 1) consists of four definite portions, *viz.*:

(1) An initial portion, O C, of constant slope (*i.e.* constant acceleration) corresponding to the starting period during which the starting rheostats are cut out from the motor circuit, full voltage being applied to the motors at the point C.

(2) A portion, C D, of gradually decreasing slope (*i.e.* gradually decreasing acceleration), corresponding to the speeding-up of the train to its maximum speed. The shape of this portion depends entirely upon the shape of the speed-torque characteristic—between the speed limits represented by the points C and D—of the driving motors. Power is cut off at D while the train is still accelerating.

(3) A coasting portion, D E, during which the train runs (without power) by its own momentum, the speed gradually decreasing due to the resistances to motion. The retardation during the coasting period is considered to be constant in the diagram, but in fact the value of the retardation changes slightly with changing speed, due to the resistances to motion varying with the speed. If these changes were taken account of, however, and the actual coasting curve were drawn on the diagram, it would be indistinguishable from a straight line. Coasting ceases at E, when the brakes are applied.

(4) A braking portion, E A, during which a high retardation is produced by the brakes, the train being brought to rest at A.



TRACTION. Fig. 1. Speed-time and distance-time curves for electric train working on suburban service.

The distance-time curve in Fig. 1 corresponds to the speed-time curve in that diagram; the points F, G, H representing the distances at the instants corresponding to the points C, D, E on the speed-time curve.

Acceleration and Retardation Values. For typical urban and suburban service, the values of acceleration, coasting retardation, and braking retardation are approximately as follow:

Mean acceleration (*i.e.* slope of O C) during starting .. .. 1·0 to 1·3 m.p h. per second.
Coasting retardation .. 0·1 m.p.h. per second.
Braking retardation .. 1·75 to 2·25 m.p.h. per second.

For modern trolley-bus services, the values are approximately:

Mean acceleration during starting.. 2 to 2·5 m.p.h. per second.
Coasting retardation .. 0·37 m.p.h. per second.
Braking retardation .. 2·5 to 3 m.p.h. per second.

Average Speed and Schedule Speed. If the total distance of the run, represented by the ordinate A J, is divided by the time of the run, represented by O A, we obtain the average, or mean running, speed. This, expressed in miles per hour, is represented by the ordinate O M in the speed-time diagram. Hence the area of the rectangle O M N A will be equal to that enclosed by the speed-time curve O C D E A, since both of these areas represent the same quantity, *viz.* the distance of the run. In other words the horizontal line M N is the mean height of the speed-time curve O C D E A.

If the time of the stop, A B, is added to the running time, O A, the quotient obtained by dividing the time, O B, into the distance, A J, is called the *schedule speed.* This, expressed in miles per hour, is represented by the ordinate O P in the speed-time diagram. The area of the rectangle O P Q B is equal to that of the rectangle O M N A, and is also equal to the area of the speed-time curve O C D E A.

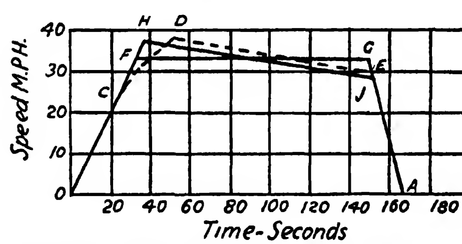
The time, O B, is called the *schedule*, or *booked time*, and is the time which is given in the time tables.

Importance of Short Stops. Observe that when the running time, O A, is relatively short, as in tramway, trolley-bus, and short-distance suburban service, the time of stop must be correspondingly short, otherwise the height of the rectangle O P Q B will be much lower than that of rectangle O M N A.

For example, if the distance between stations is 0·5 mile and the average running speed is 20 m.p.h., the schedule speeds corresponding to stops 10, 20, and 30 seconds will be 18 m.p.h., 16·35 m.p.h., and 15 m.p.h. respectively. The 30-second stop, therefore, results in a 17 per cent. reduction in schedule speed compared with a 10-second stop.

The reduced schedule speed due to prolonged station stops very seriously affects the working of railways with dense traffic (such as the London Underground railways), since it:—(1) reduces the number of trains per hour on a given length of track, (2) reduces the number of miles which a given train can run during a service period, (3) requires more rolling stock for a given volume of traffic.

Simplified Speed-Time Curves. The speed-time curve shown in Fig. 1 can be drawn only when full particulars of the train and its equipment are available. For preliminary work a diagram of simple geometrical shape is necessary, and two

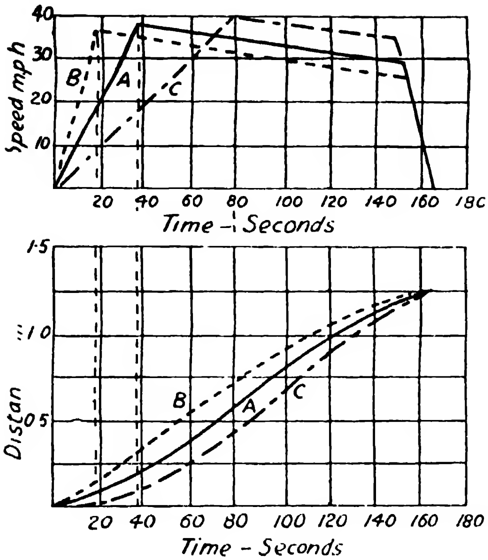


TRACTION. Fig. 2. Simplified geometrical speed-time curves for preliminary working out of a service.

suitable shapes are shown in Fig. 2. In each case the acceleration and braking retardation are the same as those in the actual speed-time curve, and, of course, the area enclosed by all the diagrams is the same. Such simplified diagrams are very useful in showing the effect of acceleration, braking retardation, maximum speed, etc., on a service. The diagrams in Fig. 3 are typical examples.

Power and Energy Requirements. The actual energy necessary for the propulsion of a car or train is expended (1) in acceleration, (2) in resistances to motion, including effects, if any, due to gravity.

The energy necessary for acceleration is, in all cases of short-distance runs, very much greater than that expended against



TRACTION. Fig. 3. Geometrical speed-time curves showing periods of acceleration, coasting, braking, with corresponding distance-time curves

the resistances to motion. The former is stored in the train or vehicle, and is recoverable during coasting or regenerative braking. But when the power brakes are applied the remaining stored energy is dissipated in the brake shoes and wheel tires. The amount of energy dissipated thereby may, in the case of short-distance runs at high schedule speeds, be as much as 70 per cent. of the total energy required for propulsion.

The energy is calculated by applying the fundamental principles of mechanics (*e.g.* energy = power × time = force × distance), and, in electric traction, is expressed in electrical units, *e.g.* kWh or Wh.

Tractive Effort. The propulsive force in all modern forms of electric traction is exerted at the rims, or treads, of the driving wheels, and such force is called tractive effort. The tractive effort required for acceleration on level track is calculated from the formula:

$F = 102\, W_e\, a$, where F is the tractive effort in lb, W_e the effective mass in tons, and a is the acceleration in miles per hour per second.

The effective mass (W_e) is from 8 to 12 per cent. greater than the dead mass, in order to take into account the force necessary for the angular acceleration of the wheels and motor armatures.

Tractive Resistance. The tractive effort required for the resistances to motion (excluding gravity) is equal to the actual value of such resistances. In traction work the tractive resistance is expressed in lb. per ton of vehicle, or train weight, and may vary between wide limits (*e.g.* 5 and 55 lb. per ton), according to the class of vehicle, road or rail surface, speed, etc.

For rail traction and suburban railway conditions the tractive resistance for preliminary calculations is assumed at an average approximate value of 10 lb. per ton; for tramway operation an average value of 20 lb. per ton is assumed; and for trolley-bus operation a value of 40 lb. per ton is assumed. These values are purely rough average values, but for the services mentioned they are quite sufficient for calculations of schedules and energy owing to the preponderating effect of acceleration.

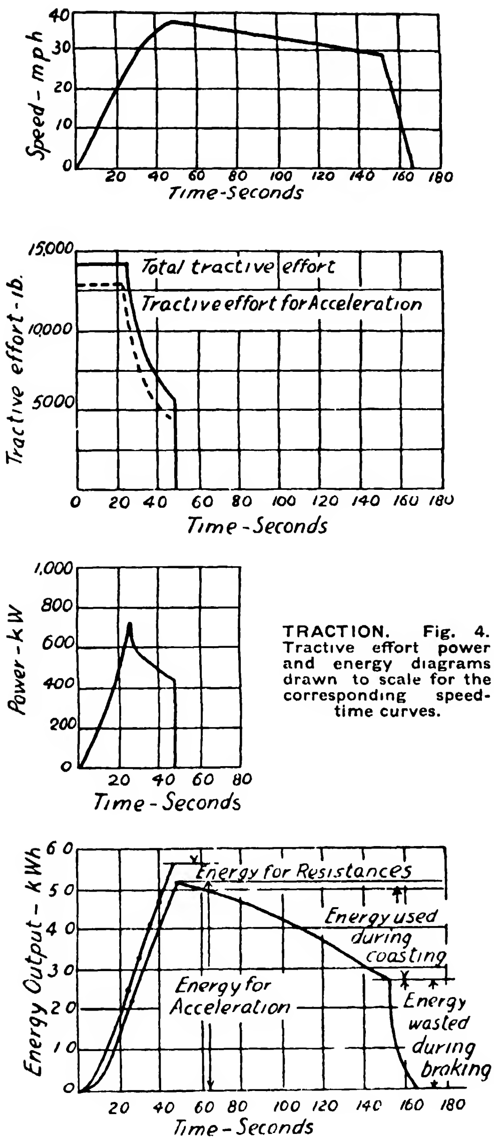
EXAMPLE. The tractive effort necessary for the propulsion of a 200-ton train at an acceleration of 1·2 m.p.h. per second on level track is calculated as follows:

Allowing 12 per cent. for the rotational inertia of the revolving parts (*i.e.* $W_e = 1{\cdot}12 \times 200 = 224$ tons), the tractive effort for acceleration $= 102 \times 224 \times 1{\cdot}2 = 27{,}400$ lb.

Allowing 10 lb. per ton for tractive resistance, the tractive effort required for resistances $= 10 \times 200 = 2{,}000$ lb. Whence the total tractive effort required for propulsion $= 27{,}400 + 2{,}000 = 29{,}400$ lb.

Gradients. The effect of gravity exerts a force which opposes motion on a rising or "up" gradient, and assists motion on a falling or "down" gradient. This force is equal to 22·4 lb. per ton for each 1 per cent. of gradient. It is commonly called the "grade resistance."

On up gradients additional tractive effort is necessary to balance the gravitational force if the acceleration or speed is to be maintained. For example, for the propulsion of the above 200-ton train at an acceleration of 1·2 m.p.h. per second up a gradient of 1 in 200 (= 100/200 = 0·5 per cent.) an additional tractive effort of (22·4 × 200 × 0·5 =) 2,240 lb. is necessary, thus making the total tractive effort equal to 29,400 + 2,240 = 31,640 lb.



TRACTION. Fig. 4. Tractive effort power and energy diagrams drawn to scale for the corresponding speed-time curves.

Tractive Effort Diagrams. An example is shown in Fig. 4, and is drawn to scale for the corresponding speed-time diagram. A 120-ton train and level track is assumed.

Power Output and Input. The power output from the driving axles at any instant is equal to the product of the corresponding values of tractive effort and speed. The power, in kilowatts, is given by :—

$P = 0{\cdot}002\ F\ V$,
where F is the tractive effort, in lb., and V the speed in m.p.h.

An example of a power diagram is shown in Fig. 4, and corresponds to the tractive-effort diagram there shown. Observe that the maximum output occurs at the end of the period of initial (constant) acceleration.

The power input, *i.e.* the power taken from the supply system at any instant, is equal to the power output plus the losses in the motors, mechanical transmission, and rheostats, if any.

During the starting period considerable losses occur in the motors and starting rheostats. The diagram for the power input during this period will, therefore, be entirely different from that for the power output, the exact form depending upon the type of motor and system of control.

Energy. The energy required for propulsion is represented by the area of the output power-time diagram.

In traction work the term Energy Consumption is applied to the energy input to the car or train from the supply or distribution system, and to enable comparisons to be readily made the energy consumption is expressed in kWh per train (or car) mile :—

$$\frac{\text{Energy input (in kWh) to the train (or car) for a given run.}}{\text{Distance of run (in miles).}}$$

Alternatively, the specific energy consumption is expressed in watt hours per ton mile :—

$$\frac{\text{Energy input (in Wh) to the train for a given run.}}{\text{Distance of run (in miles)} \times \text{weight of train (in tons).}}$$

For typical suburban service, such as the Southern Railway, average approximate calculated values of energy consumption are (for level track and a 3-coach train) :—

50 Wh per ton mile,
6 kWh per train mile (120-ton train).

Such values, however, vary with varying service conditions and train equipment.

Adhesive Weight. In order that the required tractive effort may be produced at the driving wheels, the pressure between these wheels and the rails must be sufficient to prevent slipping. The total pressure or weight on the driving wheels of a vehicle or train is called the adhesive weight.

Coefficient of Adhesion. Slipping of the driving wheels will occur when the tractive effort exceeds the frictional force between the driving wheels and track. The ratio of the tractive effort which will just cause slipping and of the adhesive weight is called the coefficient of adhesion. Its value depends upon the nature and condition of the track and wheel tires, and also upon the speed. Approximate values for steel wheels and rails and starting conditions are: 0·25 for dry rail; 0·3 for dry sanded rail; 0·15 for moist greasy rail; 0·2 for thoroughly wet rail.

Axle Loading. The permissible load which can be placed upon a pair of driving wheels is governed by the strength of the permanent way and bridge structures.

For British railway conditions the customary axle loading is about 20 tons (maximum), but in cases where the track has been specially rebuilt heavier loadings up to 22½ tons are permissible.

The number of driving axles follows directly by dividing the adhesive weight by the permissible axle loading. The value so obtained represents the minimum number of driving axles, but it does not necessarily follow that this number should be employed in practice.

Train Operation Systems

Traffic on railways may be handled either by locomotives and trailing vehicles, carrying the passengers or goods, or by motor coaches (*i.e.* passenger or goods carrying vehicles equipped with motors) with or without trailers.

Motor-Coach Trains. These consist of one or more motor coaches and a number of trailers. All coaches carry passengers—in some cases goods also—and the motor coaches are each equipped with current collectors, motors, and control gear to form independent power units. The motor coaches are electrically coupled and arranged so that the control of the entire train can be effected from the leading or driving coach.

These trains have a number of important advantages over locomotive train operation for suburban service. Thus: (1) shunting operations at terminal stations are eliminated; (2) siding accommodation, loops or turn-tables are also eliminated; (3) the passenger load is utilized for adhesion; (4) the distribution of the motive power throughout the train enables the large tractive effort necessary for rapid acceleration to be obtained with light axle loadings (the individual axle loadings being very much less than those which would be necessary for a locomotive under similar conditions); (5) the composition and length of the train can be readily changed to suit variations in the traffic, and if the proportion of motor coaches to trailer coaches is maintained constant the schedule speed and specific energy consumption will remain constant; (6) fewer signal and train movements are necessary at the terminal stations, in consequence of which a larger number of trains can enter and leave these stations during the rush-hour periods; (7) less track space and accommodation is necessary at the terminal stations.

Train-Unit. Many railways prefer to close couple one or two motor coaches and one or two trailers, and to operate these coupled coaches as a "train unit" of 2, 3 or 4 coaches, as the case may be.

Two- and three-coach train-units are employed on many suburban lines, and variations of traffic are handled by trains made up of one or more train-units. A five-coach train-unit (2 motor coaches, 3 trailers) is used on the main lines (London-Brighton-Worthing) of the Southern Railway.

Electric Locomotives

At least three types are required for an extensive main-line electrification, *viz.* (1) "express passenger" locomotives giving large outputs (1,000 to 2,000 h.p.) at high speeds (60 to 90 m.p.h.); (2) "goods" locomotives giving large outputs at low speeds; (3) "shunting" locomotives for working marshalling yards and large storage and sorting sidings.

Wheel arrangement has more variations in electric locomotives than in steam locomotives, due to the facts that the driving axles of an electric locomotive may be driven either individually or collectively, and that, in the latter case, the collective drive may be common to the whole locomotive or may consist of a number of individual groups of wheels each collectively driven.

Classification. The system of classification in general use for electric locomotives

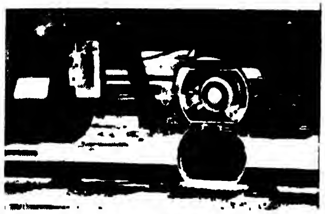


Fig. 5. Compressor contactor, a
comprising motor switches and rev

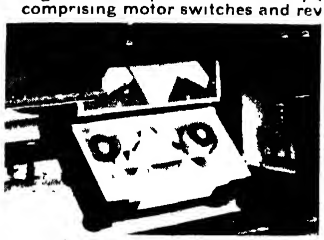


Fig. 6. Details of equipment sho
left to right are the main equipmer
on the side of the cas

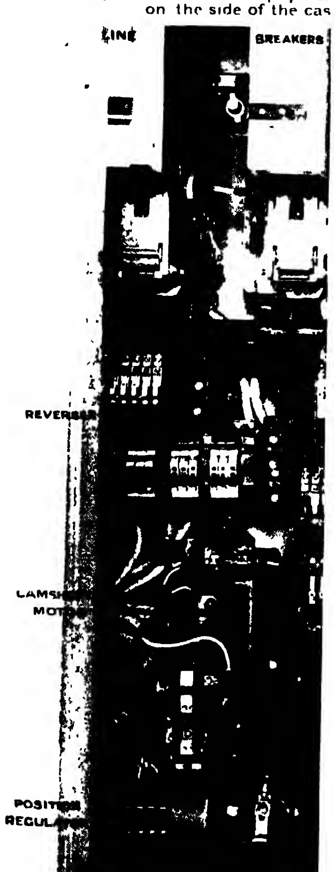


Fig. 8. Interior of a main high
railway. The control gear is
multiple-unit c

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indicates by a letter (A representing 1, B representing 2, etc.) the number of driving axles mounted in a common frame or truck, and by numerals the number of non-driving axles. The subscript $_0$ indicates that axles are individually driven.

For example, B_0B_0 indicates a double truck or bogie locomotive, each truck of which has two driving axles individually driven; BB indicates a similar locomotive, but with coupled driving wheels on each truck; B+B indicates a similar locomotive with the addition of a hinge joint between the trucks (in addition to the ordinary swivelling joints for the body); $2C_01$ indicates a 6-axle locomotive having three driving axles individually driven, a leading non-driving two-axle truck and a trailing non-driving axle; 1D1 indicates a 6-axle locomotive with four coupled driving axles in a common frame and with a leading and a trailing non-driving axle.

Power Plant. This may consist of either one or two motors of large output, or a number of motors of moderate output; the former being necessary for collective drives and the latter for individual axle drives.

The choice of the number of motors depends upon a large number of conditions, such as: supply system, voltage (in D.C. systems), wheel arrangement, system of power transmission, speed control, etc. For example, the large D.C., 3,000-volt, 4,000-h.p. locomotives of the Chicago, Milwaukee and St. Paul Railway have 12 motors; the D.C., 1,500-volt, 4,000-h.p. locomotives of the Paris-Lyons-Mediterranean Railway have four motors; the three-phase, 2,600-h.p. locomotives of the Italian State Railways have two motors; the single-phase 3,000-h.p. locomotives of the Swiss Federal Railways have four motors; the split-phase (single-phase/three-phase), 1,800-h.p. locomotives of the Hungarian State Railways have a single motor.

Number of Motors. In general, D.C. locomotives will require a minimum of four motors to obtain adequate and efficient speed control. Single-phase locomotives, however, are not subjected to such a restriction, and the number of motors can be chosen entirely from the point of view of convenience of power transmission and wheel arrangement, individual axle drive being necessary for high-speed passenger service.

Three-phase locomotives are usually equipped with two motors mechanically coupled, as the individual axle drive is unsuitable for these locomotives owing to the unequal loading of the motors with unequal wear of the wheel tires.

Power Transmission. The power may be transmitted from the motors to the driving axles in a number of ways, such as:

(1) Gear drive to individual axles from (*a*) axle-mounted motors; (*b*) frame-mounted motors; (*c*) quill mounted motors.

(2) Direct drive to individual axles from armatures directly on axles.

(3) Geared collective drive.

(4) Direct collective drive.

Diagrams showing the general arrangement of these drives are given in Figs. 5 to 9.

We can summarize the principal features and applications of different systems of power transmission as follows:

(1*a*). Geared Individual Axle Drive from Axle-mounted Motors (Fig. 10). This is the cheapest form of drive both in initial cost and maintenance, but results in relatively large uncushioned axle loads, as approximately one half of the weight of the motor must be carried unsprung on the axle. The size of motor is limited by somewhat severe physical restrictions, *viz.* the diameter of the driving wheels and the inner distance between the wheel hubs. Twin gears are necessary for large motors (when the space restrictions allow such motors to be employed). The applications are chiefly to low-speed goods and shunting locomotives and light moderate-speed passenger locomotives. Large numbers of D.C. locomotives have been built and have given satisfactory service with this drive.

(1*b*). Geared Individual Axle Drive from Frame-mounted Motors. This drive relieves the axles of heavy uncushioned loads due to the motors, which are now mounted on the frame of the locomotive. On account of the spring support between the locomotive frame and axles, the distance between a driving axle and the motor armature shaft is not a fixed quantity, and, moreover, the armature shaft may not always be parallel to the axle. The conventional gear drive is, therefore, impracticable, and a special

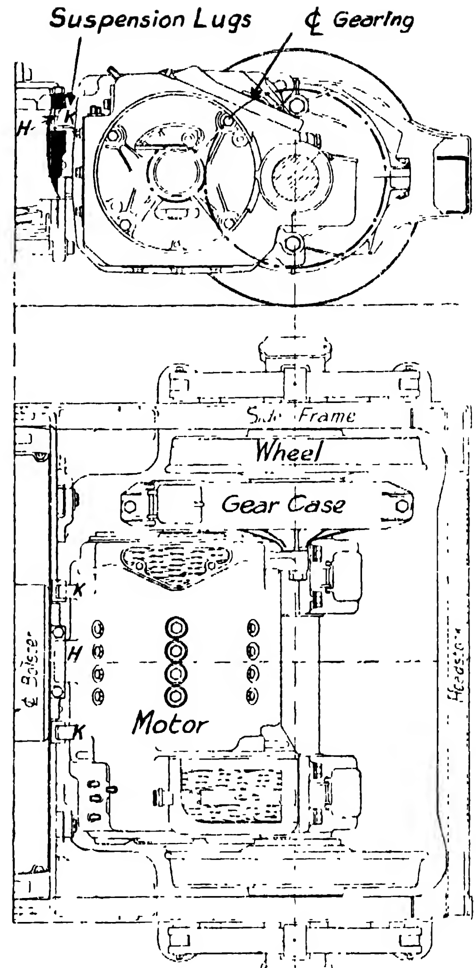
drive is necessary. The Brown-Boveri drive usually takes the form shown in Fig. 11. It is in extensive use in Switzerland, France and other countries on high-speed locomotives.

As shown in Fig. 11, the gear wheel is mounted outside the driving wheel on a stub shaft, A, fitted to the framing of the locomotive. This shaft will, therefore, always be at a fixed distance from, and parallel to, the armature shaft, thereby satisfying the conditions for a gear drive.

The gear wheel is connected to the adjacent driving wheel, B, by a universal linkwork (comprising four links, C, D, E, F) which is so designed that: (1) parallel movements of the driving axle relative to the gear-wheel shaft do not affect the uniformity in the transmission of torque, or the constancy of the angular velocities of axle and gear wheel; (2) oblique movements cause only slight deviations of these quantities in each case.

Two of the links (E, F) are pivoted in the gear wheel and are connected together by toothed segments; their outer ends are connected by two other links, C, D, to spherical headed pins, G_1, G_2, fitted to the driving wheel. The links are located in recesses in the gear wheel, and the whole transmission is enclosed in an oil-tight casing and is lubricated by forced circulation of oil.

(1c). Geared Individual-Axle Drive with Quill-mounted Motors. This drive (Fig. 17) also relieves the axles of heavy uncushioned loads, but as the gearing is arranged between the driving wheels the overall dimensions of the motor are more restricted than those of the previous drive. In consequence, the quill drive is preferred for medium outputs (up to about 500 h.p. per axle) as it is cheaper than that with universal linkwork. The quill (which surrounds the axle with sufficient clearance, nominally about $\frac{3}{4}$ inch, to allow for service movements of quill and axle) is connected to



TRACTION. Fig. 10. Geared individual axle drive from axle-mounted motor. The suspension lugs H, K, on the motor frame rest upon a bracket fitted to the transom of the truck.

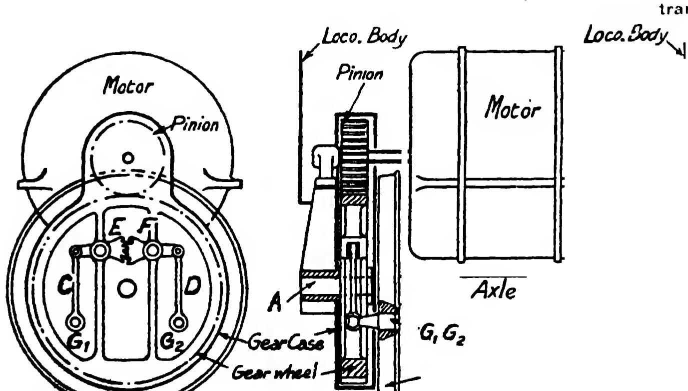
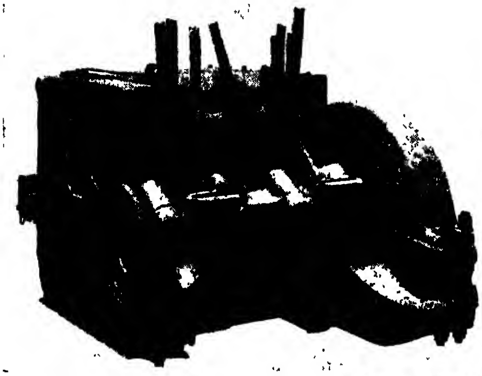
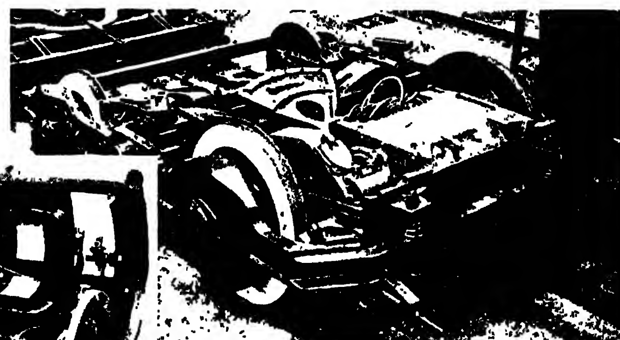


Fig. 11. The Brown-Boveri drive gear wheel is mounted outside the driving wheel on a stub shaft A fitted to the frame.



TRACTION. Fig. 12 (left). 187-h.p. (1 hour rating) traction motor to operate in pairs on an average line pressure of 1,400 V. Fig 13 (right). 430-h.p. motor of the forced ventilation type Four such single-reduction twin-geared motors are used to each locomotive

English Electric Co, Ltd



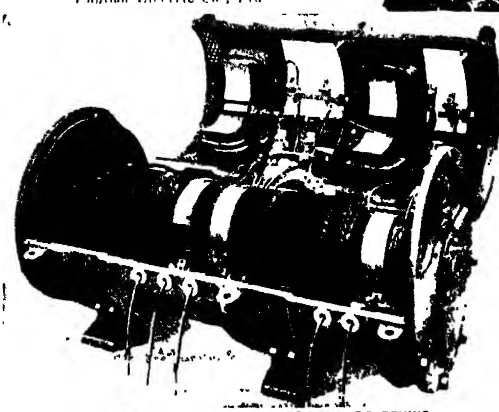
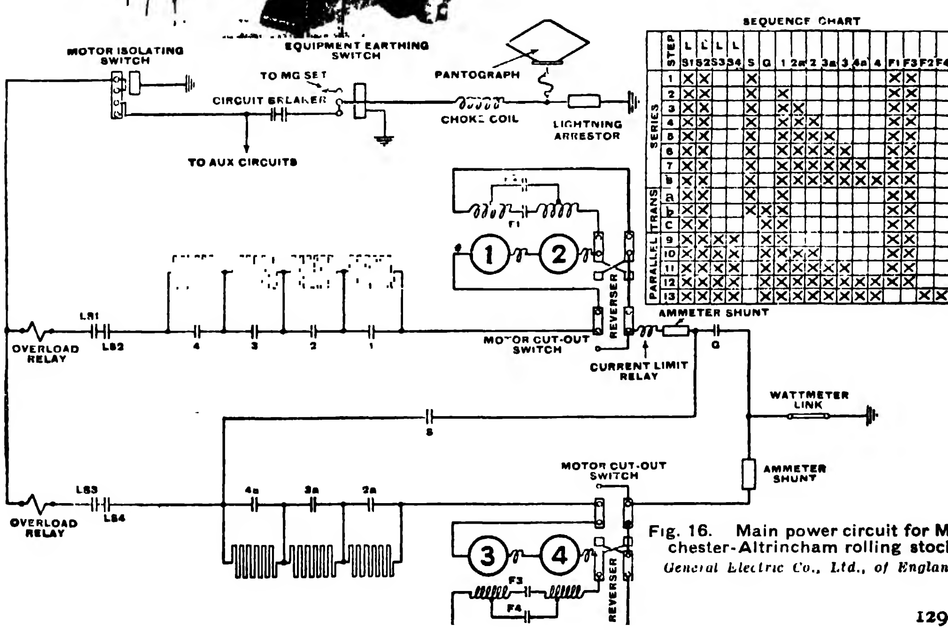


Fig. 14 (left). Motor generator set, 1,500/125 volts at 10 kW for supplying auxiliary circuits on electric locos or multiple-unit trains. Fig. 15 (above) Bogie truck of an articulated tramcar unit. Lighting and power jumpers are led out through connexion boxes.

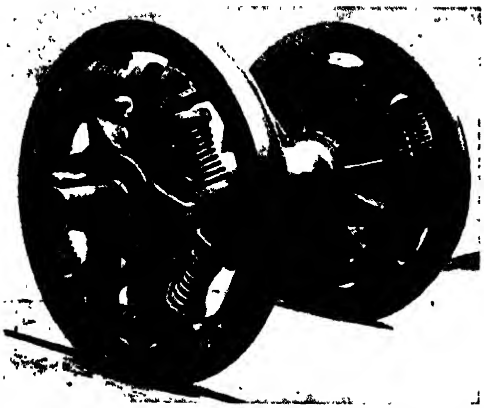
British Thomson-Houston Co, Ltd, and English Electric Co, Ltd



	STEPS	LS1	LS2	LS3	LS4	S	G	1	2a	2	3a	3	4a	4	F1	F3	F2	F4
SERIES	1	X	X			X									X	X		
	2	X	X			X		X							X	X		
	3	X	X			X		X	X						X	X		
	4	X	X			X		X	X	X					X	X		
	5	X	X			X		X	X	X	X				X	X		
	6	X	X			X		X	X	X	X	X			X	X		
	7	X	X			X		X	X	X	X	X	X		X	X		
	8	X	X			X		X	X	X	X	X	X	X	X	X		
TRANS	a	X	X			X		X							X	X		
	b	X	X			X	X	X							X	X		
	c	X	X				X	X							X	X		
PARALLEL	9	X	X	X	X		X	X							X	X		
	10	X	X	X	X		X	X	X	X					X	X		
	11	X	X	X	X		X	X	X	X	X	X			X	X		
	12	X	X	X	X		X	X	X	X	X	X	X	X	X	X		
	13	X	X	X	X		X	X	X	X	X	X	X	X			X	X

Fig. 16. Main power circuit for Manchester-Altrincham rolling stock.

General Electric Co., Ltd., of England.



TRACTION. Fig. 17. Geared individual axle drive with quill. For frame-mounted motors.

Westinghouse

each driving wheel through a double set of spiral springs ("hour-glass" type as shown in Fig. 17) which transmit the torque, half of the springs being in tension and half in compression. This drive, originated by the Westinghouse Co. and used on passenger locomotives in America, is now being used on passenger locomotives in Europe for moderate axle outputs.

(2). Direct Individual Axle Drive. This drive, with frame-mounted motors, is undesirable in practice on account of the limitations of motor output, speed, etc., which it imposes and also on account of the high cost. But the drive with the motor armatures mounted directly on the axles is a commercial proposition for high-speed D.C. locomotives, particularly in cases where a large number of driving axles is not objectionable and the output per axle is confined to relatively small powers (about 330 h.p.). The uncushioned load on the axle is then not excessive.

In such cases a special bipolar motor is employed: the field magnets are built into the locomotive frame, and the pole faces are vertical to allow for relative movements of armature and pole faces when in service.

Locomotives with such motors (built by the General Electric Co., Schenectady, U.S.A.) are in service on the New York Central and other American railways; they have run successfully at speeds of 90 m.p.h., and their maintenance has been exceptionally low.

(3) and (4). Collective Drives, Direct and Geared. The direct collective drive was developed originally for three-phase locomotives to enable frame-mounted motors to be used, and also to enable the rotors of two motors, when used, to be rigidly coupled mechanically. Due to the uniform torque of three-phase induction motors the forms of drive employed have, in general, been successful.

The most widely used form of drive is called the "Scotch Yoke" and is shown in Fig. 18. Several hundred locomotives with this drive are in service on the

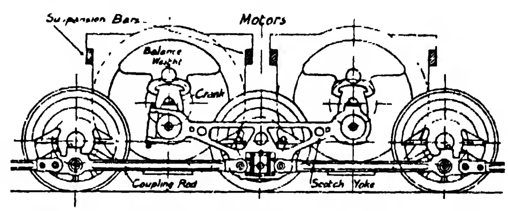


Fig. 18 The widely used "Scotch Yoke" drive as applied to three-phase locomotives.

Italian State Railways. The direct collective drive, however, has not been so satisfactory with single-phase motors, as the larger dimensions of these motors necessitate a drive with inclined connecting rods, which in many cases have caused trouble due to the vibrations arising from the pulsating torque of the driving motors.

The geared drive, however, enables higher-speed motors of smaller dimensions to be employed so that the gear shaft may be located sufficiently low in the

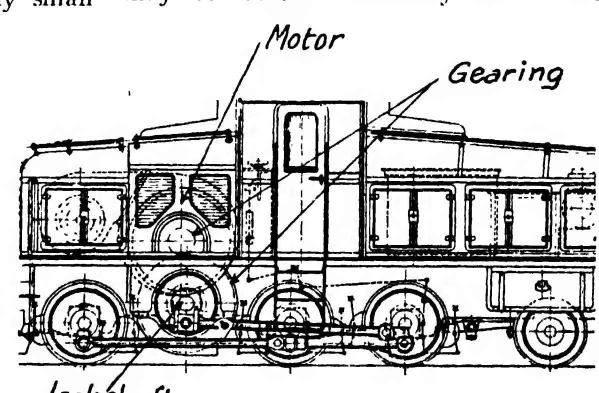


Fig. 19. Collective drive with horizontal connecting rods. This form is alternative to "Scotch Yoke."

locomotive frame to permit Scotch yokes, or alternatively, nearly horizontal connecting rods (Fig. 19) to be employed. Moreover, springs may be fitted in the pinions or gear wheels to damp the pulsations in the torque. Such geared drives are now employed extensively for heavy goods locomotives (D.C. and A.C.); they are also used on some moderate-speed passenger locomotives.

For heavy goods locomotives the geared collective drive in its group form (*e.g.* C+C or 1C+C1) with two single or twin driving motors is probably cheaper in initial cost and maintenance than the equivalent individual axle drive with axle hung motors, owing to the larger number of motors which would be necessary in the latter case.

Speed Control

In traction service the problems of speed control are more involved than those in industrial motor applications, and the requirements for suburban-line operation are entirely different from those for main-line operation.

Briefly stated these requirements are :—

Suburban Operation. The train is required to be started and accelerated as rapidly as practicable to the maximum speed corresponding to the particular service. No alternative running speeds are required for normal service, but a low speed must be provided for shunting operations.

The number of starts per hour average about 20 for ordinary suburban service, but may reach 45 per hour for urban service.

In consequence of the large number of starts per hour the energy losses during the starting period are of prime importance.

Main-Line Operation. Passenger trains are required to be started and accelerated, with moderate acceleration, to the speed suitable for the particular section of the track on which the train is running. A number of operating speeds is necessary to cover working over special track, gradients, etc. Running at speed (which may have to be controlled) is required for relatively long periods, and starting is, therefore, very infrequent.

In this case, efficient speed control and efficient operation over the range of running speeds are of prime importance.

Goods-train operation differs from passenger-train operation in two important aspects—(1) the maximum speed is lower and (2) the starting may become difficult and may be prolonged, especially if heavy trains have to be started on gradients with tractive efforts closely approaching the limiting value at which slipping of the driving wheels occurs.

In such cases the control equipment is subjected to very severe stress during the prolonged starting operations.

Motor-Coach Suburban Train Control. These trains (which almost universally have D.C. series-motor equipments) are controlled on the series-parallel multiple-unit system. Each motor coach is equipped as a complete power unit (*i.e.* with current collectors, motors, series-parallel controller and starting rheostats), and all the power units are controlled synchronously from the driving position. To enable this to be effected a remote control system is necessary, and the controllers on each motor coach must be power operated.

Power-operated Controllers. Power-operation of the series-parallel controllers may be effected by :—(1) driving the operating shaft of a drum-type or cam-shaft controller by either a small electric motor or opposed air cylinders with rack and pinion or (2) employing individual contactors (electric or pneumatic) for these controllers. Both systems, (1) and (2), have a wide application in practice, and in all cases the primary control system (which controls the operation of the motor-driven controllers or contactors) is an electrical one, *e.g.* the control of the air supply to the pneumatic cylinders of the opposed air cylinders or the pneumatic contactors is by means of electrically operated valves.

Control Bus-line. The operating, or control, circuits of the pilot motors, contactors, or electro-pneumatic valves, as the case may be, are connected to a control circuit cable or control bus-line, which runs the length of each coach (whether motor coach or trailer). This cable is made continuous throughout the train by coupler sockets and jumpers between the coaches.

Driving Controllers. Driving or master controllers are connected to this cable at all driving positions on motor coaches and trailers (if any), and a suitable supply (for the control circuit) may be connected to each master controller through isolating switches and fuses. Hence, by the operation of *one* master controller, the series-parallel controller on every motor coach in the train will function.

To enable any defective controller or motor in the train to be cut out independent of the remaining equipment, a special cut-out or isolating switch is inserted in the control circuit of each coach.

With such a remote-control system automatic "notching-up" of the series-parallel controllers throughout the train may be obtained by means of current-limiting relays. A current-limiting, or accelerating, relay is required for *each* series-parallel controller, and the "current" coil of the relay is connected in the circuit of one of the appropriate main motors. The principle of operation is somewhat similar to that employed in automatic starters (series-relay type) for industrial motors.

Locomotive-Control Systems. In all except the very smallest locomotives a remote-control system is employed, *i.e.* the controller proper is power operated, and the supply of energy to its control circuit is controlled by a small master or driving controller operated by the driver. Non-automatic control systems are customary in D.C. and single-phase equipments, but automatic control is usually employed with three-phase equipments.

In all large locomotives the extended or double series-parallel system of D.C. control (in which three combinations of the motors, *viz.* series, series-parallel, parallel, are used) is employed. In addition, field control—by tapping or shunting the field circuits—is required for passenger locomotives. Regenerative braking may also be required. Provision must also be made for operating the locomotive with one pair of the motors cut out if one motor becomes defective.

The main controller is of the contactor type, with either individual or cam-operated contactors. In each case cam-operated groups of contactors are employed for changing the motor combinations and for changing the connexions from motoring to regenerative braking.

Regenerative Braking. In obtaining regenerative braking with series-motor equipments, the machines are connected to the supply system normally as motors, and the fields are over-excited by means of an exciter, the control of the excitation of which provides the means of regulating the braking torque or effort. Stability in operation is obtained either by differential compounding the exciter, or by means of stabilizing resistances connected in the exciter circuit.

Single-Phase Locomotive Control. The single-phase traction motor is inherently a low-voltage machine (maximum voltage, for large motors, about 450 volts). A transformer, therefore, is necessary to obtain a suitable operating voltage for the motors on a locomotive. This transformer may, conveniently, also be used for starting and speed control, if suitable tappings are provided on the secondary winding, *i.e.* the entire starting and speed control may be effected by supplying suitable voltages to the motor.

The equipment for this purpose takes the form of either a motor-driven tapping switch, or a group of individually operated contactors.

Three-Phase Locomotive Control. Three-phase locomotives are equipped with induction motors, which are started by inserting and cutting out resistance from the rotor circuits. Liquid rheostats (*see* Liquid Resistance) are usually employed for this purpose, and the control of the resistance is effected by altering the level of the liquid, compressed air being used for this operation. Usually the control is automatic so as to maintain constant power (watts) input to the motors.

Speed control is effected by either pole changing or cascading, or by a combination of these methods. Four running speeds (in the ratio of either 1 : 2 : 3 : 4, or 1 : 1·33 : 2 : 2·66) can be obtained by pole changing alone, or by a combination of pole changing and cascading.

CURRENT COLLECTION

On tramways and trolley-bus systems the maximum current required by the car or vehicle is about 200 amps. at speeds up

to about 10 m.p.h. At the maximum speed (about 25 m.p.h.) the current will be about 90 amps.

On suburban railways the maximum current required by a train may reach 1,500 amps. to 3,000 amps. (according to the make-up of the train) on 600-volt systems. Such currents will be required during starting at speeds up to about 25 m.p.h., above which speed the current decreases as the speed increases. At the maximum speed (about 40 m.p.h.) the current may be between 750 amps. and 1,500 amps., according to the make-up of the train. Suburban trains working at 1,500 volts will require proportionately smaller currents.

Large 1,500-volt D.C. passenger locomotives may require currents up to 2,500 amps. at speeds up to about 40 m.p.h., and currents of about 1,500 amps. at the maximum speed, 90 to 100 m.ph.

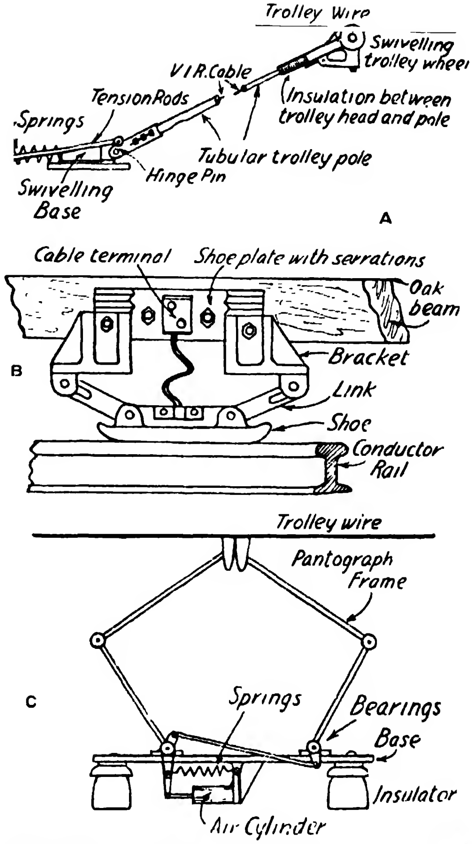
Large 1,500-volt D.C. goods locomotives may require maximum currents up to 2,000 amps. at speeds up to about 20 m p.h.; the current decreasing to about 800 amps. at 40 m.p.h.

Large single-phase (15,000-volt) locomotives may require currents up to about 200 amps. at speeds up to about 20 or 40 m.p.h. according to the service (*e.g.* goods or passenger respectively). At the maximum speed (75 m.p.h.) the current may be about 150 amps.

Current Collectors. The type of current collector to be employed depends upon the nature and position of the conductor from which current is to be obtained, the magnitude of the current, and the speed. The types in use are: trolley wheel, shoe, bow, pantograph. Sketches of these are shown in Fig. 20.

Trolley-wheel Collector. This is used universally in this country and America on tramways and trolley-bus routes. Details are given under Trolley-Bus.

Shoe Collector. This is used for collecting currents from conductor rails, and is the standard type of current collector for 600-volt D.C. motor coaches and locomotives. The contact shoe, of cast steel, and weighing about 30 to 40 lb., rests upon the surface of the conductor rail by its own weight, and is suspended by slotted links from adjustable brackets fixed to a shoe plate, the latter being carried

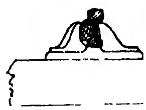


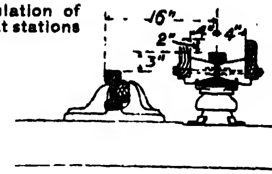
TRACTION Fig. 20 Forms of current collectors (A) Trolley wheel, (B) shoe; (C) pantograph.

from a wooden (oak) beam fixed to the axle boxes or motor frame according to the position of the conductor rail. With insulated return systems two collector shoes are necessary: one of these is carried from the axle boxes, and the other from one of the motor frames.

Bow Collector. This is a sliding contact collector for collecting relatively small currents from overhead trolley wires. The contact member is a strip of aluminium, which is held in a light tubular frame or bow, and is pressed against the trolley wire by springs. The bow framework, therefore, is alive when in use, and it must be mounted on insulators. Bow collectors cannot be used on open-type double-deck cars, but are frequently used on single-deck cars in Europe. Such collectors have an advantage over the trolley-wheel collector in that no switching or point frogs are necessary at junctions in the overhead

TRACTION. Fig. 21. Mounting and insulation of conductor rails. Wooden protection used at stations is also shown.





conductor. The bow may also be arranged to accommodate itself automatically to either direction of motion.

Pantograph Collector. This is preferable to the bow collector for heavy current collection from overhead conductors, as it will operate in either direction of motion. Moreover, a large contact surface may be obtained when required, and the contact surface is always maintained parallel to the trolley wire.

For heavy currents the contact portion consists of one or two pressed steel pans with insert copper strips and receptacles for lubricating grease. The pans are attached to the apex of a light pentagonal framework which is mounted on insulators on the roof of the locomotive. The collector is maintained in the raised or operating position by air pressure in pneumatic cylinders acting against springs, which lower the collector in when the air pressure is released. The framework may be latched in its lowest position.

Contact Systems. The contact portion of the distribution system from which the current is actually collected may consist of either (1) steel conductor rails laid on the surface parallel to the track rails, or (2) bare copper conductors suspended longitudinally above the track or roadway.

Conductor Rails. These are used only when heavy currents at low voltages are required, *e.g.* 600 volts D.C. electric railways. The rails consist of high conductivity steel (specific resistance about 6½ times that of copper) weighing about 100 lb. per yard. The width of the head at the contact surface is about 2½ in., and the cross-section is usually of the flat-bottomed T or Vignoles type.

For 600-V surface railways in this country the conductor rails are mounted on petticoated pedestal type porcelain insulators, which rest directly upon the sleepers and are secured in position by two malleable iron clamps. The arrangement is shown in Fig. 21, which also shows the wooden protection (fitted at stations) and the standard location.

Trolley Wires. Hard-drawn copper is usually employed for the overhead contact conductors on tramways, trolley-bus routes and railways, but in some cases alloyed copper is used on account of its longer wearing qualities. On some American railways a steel contact wire is employed in order to cheapen the cost of contact-wire renewals. The steel contact wire is clipped throughout its length to a hard-drawn copper wire, which is used for current-carrying purposes.

Suspension of Trolley Wire. A non-sagging trolley wire is essential to obtain sparkless current collection at high, and also at moderate, speeds. Moreover, the suspended wire must possess vertical flexibility with no hard spots. The ordinary direct suspension as employed on tramways and trolley-bus routes (*see* page 1336) is impracticable, because a non-sagging trolley wire would require suspension at intervals of about 10 to 15 ft., and each suspension point would constitute a "hard spot" for the pantograph collector.

Catenary Suspension. This method, shown in Fig. 22, enables short intervals between the suspension points of the contact wire to be obtained without the necessity for insulated hangers at these points. Hard spots on the contact wire

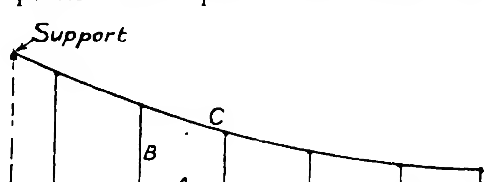
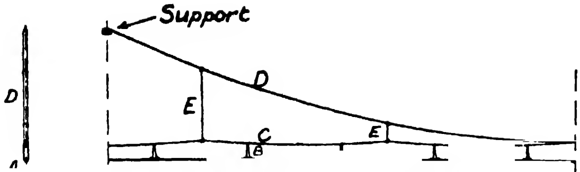


Fig. 22. Catenary suspension for overhead wire.

are, therefore, entirely avoided. The contact wire, A, is suspended at short intervals (10 to 15 ft.) by light clips and droppers, B, from a suspension wire, C (called the "catenary" wire or "messenger"), which is suspended, with considerable sag (5 to 10 ft.) between insulated supports placed at moderate distances apart (150 to 300 ft.). The object of the large sag in the catenary wire is to main-



TRACTION. Fig. 23. Compound catenary suspension.

tain the position of the trolley wire approximately constant, regardless of temperature variation in practice. The trolley wire is divided into sections (½ to 1 mile), and each section is dead ended and strained to a given tension when erected.

Compound Catenary Suspension. In the alternative construction (Fig. 23) the contact wire, A, is supported by looped droppers, B, from an intermediate wire, C, which is suspended by droppers, E, from the catenary wire, D. This system gives greater flexibility to the trolley wire and enables the latter to be fitted with straining devices to maintain a constant tension in the trolley wire at all temperatures, which is necessary when the temperature range is large (as in some parts of Europe and in Scandinavia).

TRAFFIC CONTROL LIGHT SIGNALS, AUTOMATIC

By H. H. Harrison, M.Eng., M.I.E.E., Joint-Author of "Automatic Street Traffic Signalling"

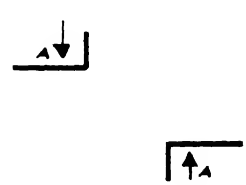
In this article, written by a specialist in one of the most recent applications of electrical relay methods, both the earlier fixed-time cycle and the vehicle-actuated systems are described. Necessarily fuller details are given of the latter more important, though more complicated system. Both the "Electromatic" and the "Autoflex" systems are covered. See Contactor; Neon Tube; Relay.

The now familiar automatic three-light signals were generally introduced in England for the control of street traffic in the year 1928. The intervening period has been marked by a very vigorous development in the signals themselves and in their control. More important still is the fact that the introduction of such signals has compelled street authorities to make a much more careful study of the nature of street traffic than hitherto. Thus the effects of spacing and the various classes of vehicles on traffic flow have been very widely investigated.

If we consider a simple intersection A–B (Fig. 1), consisting of two lanes of two-way traffic, then, neglecting left and right-hand turns, two-way traffic movements will take place alternately at right angles to each other. These movements will be controlled by signals at the corners of the intersections, and these signals will alternately give the right of way on the respective phases A and B.

The signal lanterns are provided with three lenses, giving in turn a red or "stop" indication, an amber or "caution" signal, and a green or "go" signal. Where a line of waiting traffic is about to be given the right of way, amber and red are simultaneously displayed, and this is an indication to the waiting vehicles to prepare to start. Amber after green means "stop" before entering the intersection unless the vehicle is just entering or is partly across the intersection.

Fixed-time Cycle Apparatus. Until comparatively recently signalling was generally accomplished by three-light signals switched in and out in correct sequence by means of a controlling mechanism or controller.

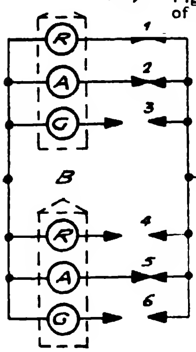


TRAFFIC CONTROL SIGNALS. Fig. 1. Simple two-lane intersection with two-way traffic.

Fig. 2 (*a*) shows diagrammatically the switching contacts 1–6 of such a controller with the lamp circuits controlled by them. Fig. 2 (*b*) shows how the complete time of a cycle is divided up on the two routes or "phases." Equal "go" periods are assumed, but if traffic is heavier on one phase than on the other, the timing is altered to suit. Usually the green period can be varied between 20–70 seconds, while the amber period, which is, of course, much shorter, is round about 3–5 seconds. Fig. 2 (*c*) is a chart showing the sequence

TRAFFIC CONTROL SIGNALS. Fig. 2. Chart showing sequence of contact closure during the four parts of the complete cycle.

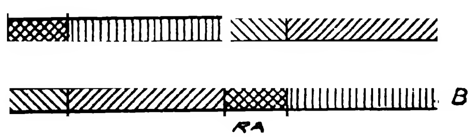
(a)



(c)

	Contacts					
	1	2	3	4	5	6
1	X	X			X	
2			X	X		
3		X		X	X	
4	X					X

(b)



of contact closure during the four parts of the complete cycle.

The contacts 1–6 are closed by suitable cams mounted on a shaft which is rotated at a constant, slow, and adjustable speed, so that the various signal indications are displayed at the right times and for the desired length of time.

A simple method of doing this is shown in Fig. 3, where the three cams, their contact springs, and the circuits which the latter control in order to operate the various signals in the two lanterns, are laid out diagrammatically.

The shaft with its battery of cams is driven by an electro-magnetic ratchet and pawl mechanism, consisting of the ratchet wheel RW and a driving magnet DM. By suitable choice of the number of teeth on the ratchet wheel, and the rate at which the driving magnet is impulsed, the speed of rotation of the shaft may be made anything desired within the usual limits.

Fig. 3 (*b*) shows in polar form the subdivision of the cycle for the two phases of traffic. The overlap of the red and amber lights is shown by the hatched sectors in the two diagrams.

Such an arrangement as that described is known as a fixed-time cycle system. The cycle time can be altered from time to time to meet hourly or daily trends, and in spite of certain disadvantages has given good service in the past. The drawback to this method is that with no traffic on one route and average traffic on the other, the latter is held up unnecessarily. The serious aspect of this is that maximum traffic capacity is not being got out of the routes of which the intersection forms part.

Fig. 4 shows five consecutive cycles abstracted from a sample of traffic recorded on a busy intersection. The chain dotted horizontal lines are drawn to represent the "go" periods of a fixed time controller. In some cases it will be seen that the traffic is too heavy for the "go" period allowed and a "spill-over" occurs to the next recurrence of that phase. On

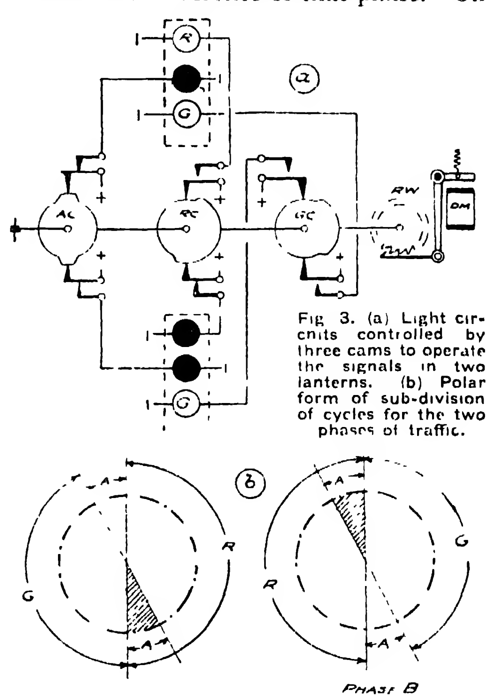


Fig. 3. (a) Light circuits controlled by three cams to operate the signals in two lanterns. (b) Polar form of sub-division of cycles for the two phases of traffic.

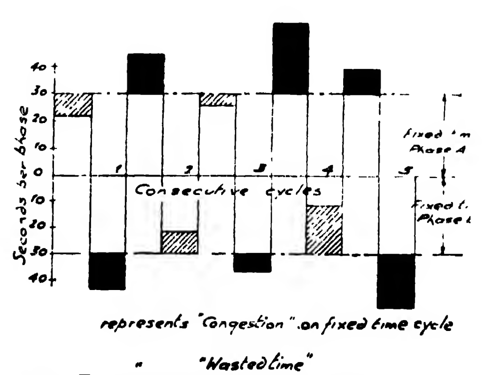
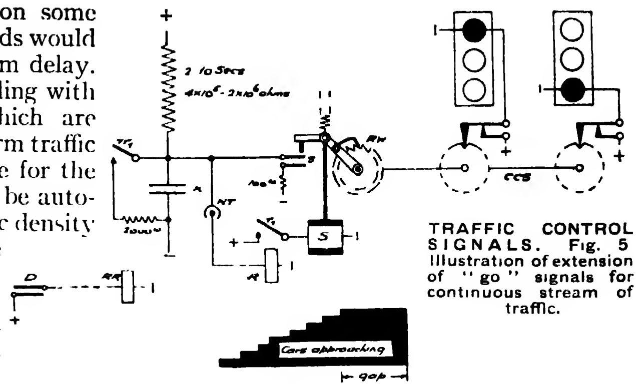


Fig. 4. Five consecutive cycles abstracted from a sample of traffic recorded on a busy intersection.

the other hand, the traffic on some phases is so light that 30 seconds would suffice to pass it with minimum delay.

The only possible way of dealing with such violent fluctuations, which are typical of the apparently uniform traffic at a busy section, is to arrange for the times of the " go " periods to be automatically adjusted to the traffic density from cycle to cycle. The rate of approach of traffic on each phase is the controlling factor, and the utilization of this principle has resulted in the production of the vehicle-actuated system of traffic control.



TRAFFIC CONTROL SIGNALS. Fig. 5
Illustration of extension of " go " signals for continuous stream of traffic.

The Vehicle-Actuated System. Two such systems are available at the present moment, the " Electromatic " (the pioneer system) made by the Automatic Electric Co., Ltd., of Liverpool, and the " Autoflex " produced by the Siemens and General Electric Railway Signal Co., Ltd., The general principles on which these systems operate are practically the same.

A method by which the operation of the display of a " go " signal may be extended in accordance with a continuous stream of traffic is diagrammatically indicated in Fig. 5. The controller cam-shaft CC is rotated by means of the solenoid S and the ratchet and pawl mechanism operated by this. A condenser K is permanently across the mains through a high resistance, and when it attains a definite potential, the neon tube NT becomes conductive and passes current which operates relay R. R closes a circuit for the solenoid S and the cam-shaft makes one step. The armature of solenoid S carries a horizontal arm which, as it moves downwards, closes two contact springs *s*, thus short-circuiting condenser K. The condenser then commences to charge up again and the process is repeated. In this way the controller acts as an ordinary fixed time apparatus, the length of the " go " period depending upon the value given to the series charging resistance.

If now a contact-closing device or vehicle detector is placed in the road by which the traffic is approaching and each vehicle closes the contacts of D so that a road relay RR in the controller is operated and places a shunt of 2,000 ohms around the condenser, the latter will discharge and its voltage fall. The amount by which the pressure on the condenser falls will depend upon the duration of the contact at D, and this will be inversely proportional to the speed of the vehicle passing over D, a slow-moving vehicle discharging the condenser to a greater extent that a fast-moving one.

Ignoring, for the purposes of simplification, the other road for the moment, the first vehicle approaching the intersection would, if a red signal is being displayed, change this to green. If now a uniform stream of approaching vehicles is maintained, K will be constantly discharging, and its rise to the critical voltage which determines the operation of the neon tube NT will be continually hindered. So long as the traffic flow is maintained, the right of way will be held on that phase, but should the rate of flow diminish (a gap occurs, see diagram in the lower part of Fig. 5) the potential across K will reach the necessary value and effect a switching change, removing the green indication from one phase and transferring it to the other. At the same time a red indication is substituted for the previous green one on the phase which had been passing traffic.

This arrangement, which only serves to illustrate the principle of automatic extension of the " go " period proportional to the volume of traffic flowing, is imperfect in several respects.

Obviously, if there were a constant stream of traffic on one phase and this stream had secured the right of way, it would hold it indefinitely, and the waiting traffic on the other phase would be unduly delayed until such time as a gap occurred in the moving traffic stream. In the

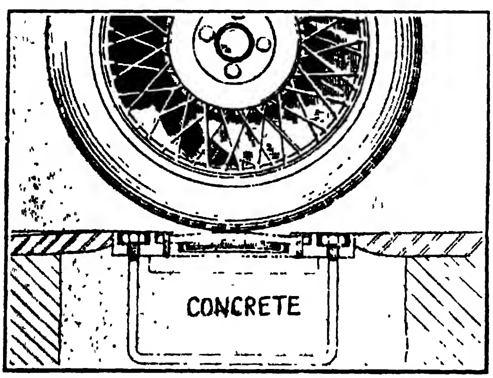
actual apparatus, means are provided to prevent this condition arising.

The practical vehicle-actuated system consists of three pieces of apparatus :—

1. The Detector, a device for indicating the approach of a vehicle.
2. The Controller, and
3. The Signal Lanterns.

The Detector. The detectors are contact-making devices of three general types, *viz.* road vehicle detectors, tram detectors and pedestrian push buttons.

Fig. 6 is a cross-section of a pressure-operated unit which is set flush with the surface of the road and extends over approximately half the width of this and at a distance from the intersection depen-



TRAFFIC CONTROL SIGNALS Fig. 6 Cross-section of pressure-operated unit, set flush with the roadway

dent upon local conditions and the average speed of the traffic. This detector consists of two steel strips lying parallel and spaced at a suitable distance apart. The steel strips, together with their attached flexible electrical connexions, are moulded into a substantial rubber envelope which effectually excludes moisture or other foreign matter, and prevents oxidation. Details of the detector are given in Fig. 7. The detector establishes a momentary contact by the flexing of the upper strip caused by a vehicle passing over it. Being pressure operated only, its operation is unaffected by road dirt, snow, or even ice.

Fig. 8 shows in diagrammatic form the "Autoflex" detector which operates on an entirely different principle from that last described. A rubber block RB has two cavities traversing the whole of its length. One end of these cavities is blocked up but the other end is closed around two metal tubes. The whole is enclosed in a casting and is covered with a rubber covering plate CP which is clamped to the casting by suitable flanges. As a vehicle passes over CP the two cavities are compressed in turn and expel the air contained in them.

This air is passed through the tubes to a bellows contact-making arrangement shown in the upper part of the figure. P is a plate of insulating material which is hinged at H to the frame of the contact box (not shown). It carries a movable contact MC adapted to press against a fixed contact FC. When air is expelled from either of the cavities in RB it is conducted to the bellows B and, expanding this, effects closure of the contacts. Two such contact mechanisms may be fitted, one to each cavity, and the order in which they come into operation can be made to determine whether the passage of the

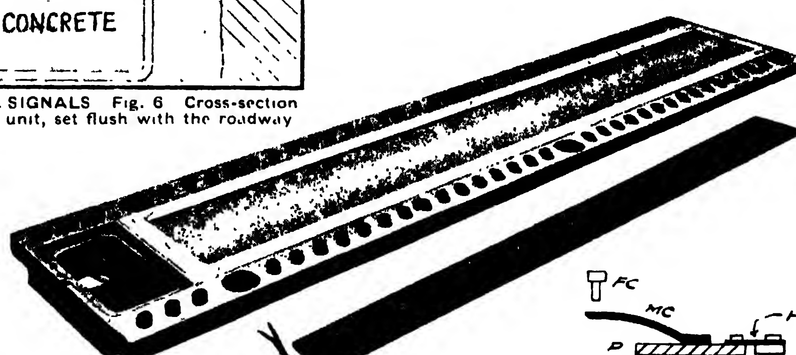


Fig. 7. Details of pressure-operated detector unit. *Automatic Electric Co., Ltd*

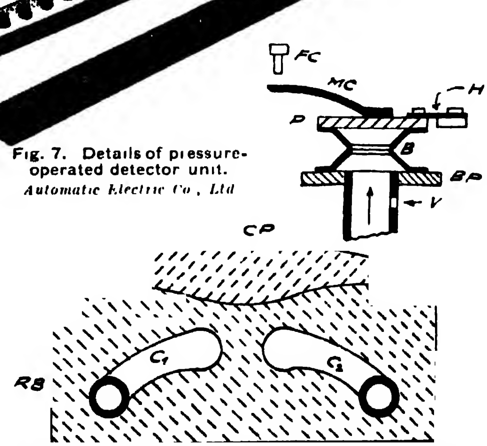


Fig. 8. Diagrammatic sections of "Autoflex" detector. RB is rubber block, CP covering plate, P insulated plate, B bellows, FC and MC fixed and movable contacts respectively. (Siemens.)

vehicle shall be effective or not with respect to the controller. This "unilateral" feature is sometimes a requirement and is met in the case of the detector previously described by dividing the top steel plate into two portions.

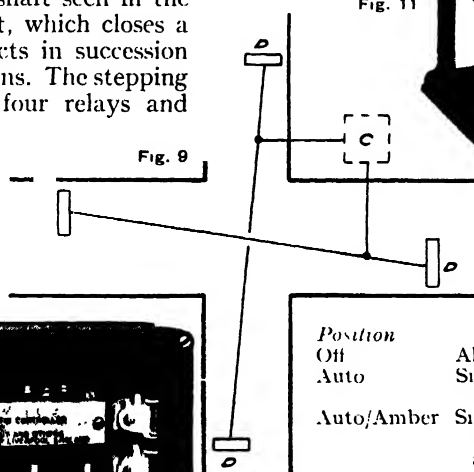
Fig. 9 shows the arrangement of the detectors at a simple intersection. The N–S detectors D are connected electrically together and to the controller C, and the same is true for those detectors on the other phase. The detectors are placed at a suitable distance from the stop line having regard to the braking possibilities of the traffic. Tram detectors are available in a variety of forms.

The Controller. The controller unit is shown in Fig. 10. It automatically performs the necessary switching operations to the signals in accordance with the indications received from the detectors. The switching is accomplished by the step-by-step action of the cam-shaft seen in the upper portion of the unit, which closes a group of electrical contacts in succession in six different combinations. The stepping action is controlled by four relays and two timing circuits.

In the lower portion of the unit the various switches and adjustable timing resistance switches will be seen.

Fig. 11 shows a pillar type of controller casing with the door open. The controller unit is in the upper part of the casing. Access to the controller can be obtained by authorized persons, and a key-controlled switch can be operated to any one of six positions giving the conditions which are noted in tabular form below.

Fig. 11



TRAFFIC CONTROL SIGNALS. Fig. 9 (left). Arrangement of detectors at a simple intersection. Fig. 11 (above). Pillar type of controller casing with door removed.

Position	*Condition*
Off	All signal lights off.
Auto	Signal lights controlled automatically.
Auto/Amber	Signal lights controlled automatically and amber globe lights on Time switch on.
Amber	Amber globe lights only.
Manual	Manual operation.
All Red	All signal lights display red.

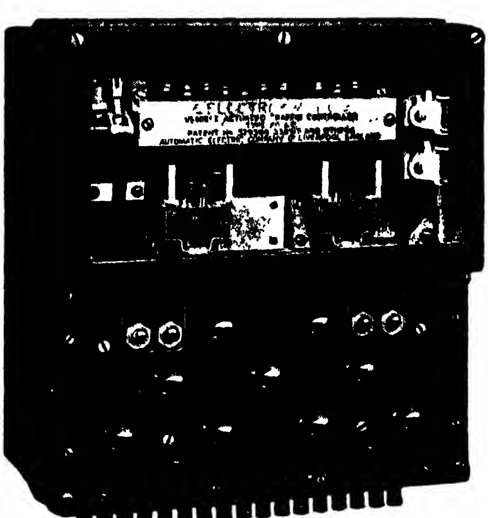


Fig. 10. Exterior view of controller unit. The contactor cam-shaft and timing switches can be seen. *Automatic Electric Co., Ltd.*

A push button is provided for manual control, which is sometimes necessitated by such things as processions and other special occasions.

The object of the time switch is to switch the signals "off" late at night and to switch them "on" again in the morning.

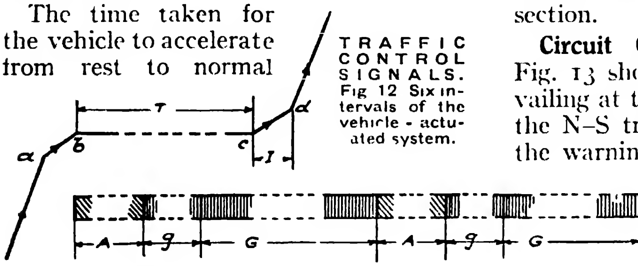
Operation of the Vehicle-Actuated System. The complete cycle is divided into six intervals as against four in the fixed-time cycle system.

This is shown in the diagram Fig. 12, from which it will be seen that the "go" period is in two portions, a short interval marked *g* preceding the main interval G.

The object of this arrangement is as follows:

In the upper portion of Fig. 12 the course of the front vehicle of a moving column is indicated by the thick sloping line. Between *a* and *b* it decelerates and between *b* and *c* it is actually stationary. It starts in motion again at *c* and from *c* to *d* accelerates to normal speed which it attains at *d*.

The time taken for the vehicle to accelerate from rest to normal speed is known as the "initial" interval I and is prefixed to each phase of traffic movement with the object of allowing the stationary waiting vehicles to get into motion. The second period G, which is extensible by the action of vehicles approaching after the waiting train is in motion, need only be that necessary for a vehicle to travel from the detector and across the intersection. This interval is known as the vehicle interval and can therefore be shorter than it would otherwise have to be made, and this leads to efficiency, since the rate of approach must not fall below a certain minimum if the right of way is to be held against traffic waiting on the other phase.



TRAFFIC CONTROL SIGNALS. Fig 12 Six intervals of the vehicle - actuated system.

Now, as previously explained, it must not be possible for the right of way to be held indefinitely on one phase, and to prevent this a second timing circuit is connected up at this stage which will forcibly transfer the "go" signal from the moving stream and give it to the waiting traffic. This timing circuit is so arranged that the transfer takes place after a certain maximum period has elapsed—say 50 seconds. In the case of a change of right of way, due to the intervention of the maximum period timer, the intervening amber period is increased by 2 seconds. The object of this increase is the following. If a traffic stream loses the right of way by reason of its diminishing rate of flow, a short amber signal will suffice, since the first moving vehicle approaching after the gap has occurred will not have reached its detector and will therefore have ample braking distance. When, however, a continuous traffic flow is suddenly interrupted, under the conditions explained above, a longer amber interval is necessary to allow moving vehicles which have crossed the stop line to clear the intersection.

Circuit Operation of the Controller. Fig. 13 shows the circuit conditions prevailing at the instant the "go" signal for the N-S traffic has been withdrawn and the warning amber signal has been substituted. Road relay D previously operated by traffic passing over one of the two

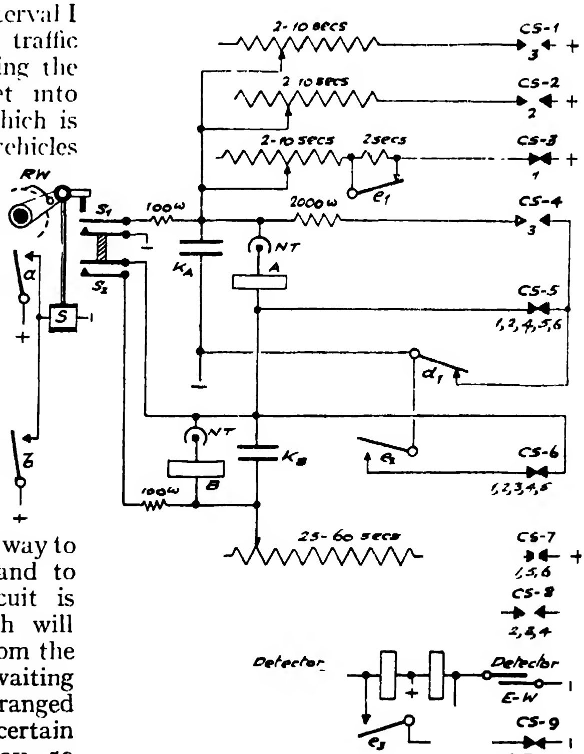


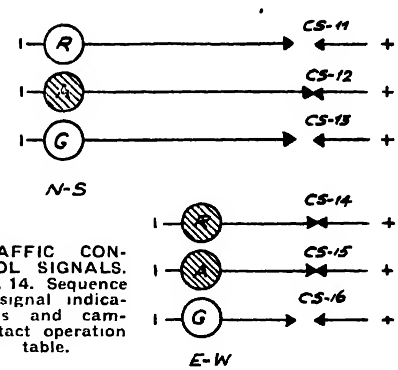
Fig. 13. Controller circuit conditions at instant that "go" for N-S traffic has been withdrawn and amber substituted.

E–W detectors is locked *via* its contact d_2 and cam springs CS 10. At d_1 and CS 5 relay A and neon tube NT are connected across the condenser K_A. When the condenser reaches the striking voltage of the neon tube, relay A operates. At its contact *a* it completes a circuit for the solenoid magnet SM and the cam-shaft makes one step, moving to its second position. While the cam-shaft was in the first position the condenser K_B forming part of the maximum period charging circuit was steadily charging over the circuit —ve, relay contact d_1, GS 5, condenser charging resistance, CS 7 to +ve. This circuit is broken when the cam-shaft steps from the first to the second position, but immediately re-established at the second position by the closure of CS 8. When the solenoid operates on the first step two pairs of contact springs s_1 and s_2 are operated and place 100-ohm shunts around both condensers, discharging both these and " re-setting " their timing circuits.

Initial Interval. In the second position of the cam-shaft the charging circuit for condenser K_A is re-established through cam springs CS 2 and a timing resistance which can be set within the limits of 2–10 seconds by a switch external to the controller unit case (*see* Fig. 10). At the termination of this interval condenser K_A reaches the striking voltage of the neon tube NT and relay A again operates. This results in the cam-shaft being stepped on to the third position.

Vehicle Interval. Two circuit changes are made in the third position. The locking circuit for relay D is opened at CS 10 so that each time a vehicle passes over the E–W detectors, relay D operates and releases. This constitutes the means by which the " go " period is increased proportionally to the traffic flow on that phase, each operation of relay D placing a resistance of 2,000 ohms around condenser K_A *via* CS 4, relay contact d_1 to negative side of condenser. The second circuit change is the substitution at CS 1 of another timing resistance.

Each time that relay D operates it partially discharges condenser K_A and thus extends the " go " period. Provided no traffic is waiting on the other phase the " go " signal will be displayed permanently.



TRAFFIC CONTROL SIGNALS. Fig. 14. Sequence of signal indications and cam-contact operation table.

Cam contact Operation Table.						
Cam Springs No	11	12	13	14	15	16
Shaft Posn 1		X		X	X	
" 2	X					X
" 3	X					X
" 4	X	X			X	
" 5			X	X		
" 6			X	X		

Maximum Period. The instant a vehicle passes over one of the N–S detectors, relay E operates and locks up *via* CS 9. This applies a charging voltage to condenser K_B from —ve, contacts e_2, CS 6, condenser, 25–60 secs. charging resistance CS 8 to +ve.

After the selected maximum period has expired, the voltage across K_B rises to the striking voltage of NT and relay B operates the pulsing solenoid magnet which causes the shaft to take the fourth step, removing the green signal from the E–W phase and displaying amber to both phases. The operation of the solenoid magnet has re-set both condensers by the means already explained. The fifth and sixth steps are effected in exactly the same way as already explained for the second and third, other timing resistances and cam springs coming into play. Fig. 14 shows the sequence of signal indications.

"Progressive" Control. A recent development of the vehicle-actuated system is an interlinking "progressive" control (as in the Marylebone Road, London), so that traffic movements are adjusted to meet variable density requirements with a minimum of waiting time for side road traffic. A traffic " integrator " permits a change in cycle periods so many times per hour in accordance with the general ebb and flow of traffic.

TRANSFORMERS IN MODERN PRACTICE

By S. Austen Stigant, M.I.E.E., F.Am.I.E.E.

Transformer engineering is a large subject in itself, requiring for its fullest comprehension much specialized study. Here the subject, in both theory and application in power and general work, is adequately outlined by an acknowledged authority. For individual forms and applications see the many detail headings, as Auto-Transformer ; Bus-bar Transformer ; Current Transformer ; Earths ; H.F. Furnace ; Sub-Station ; Welding ; X-Rays, etc. See also Electro-Magnetism ; Induction.

A transformer is a stationary piece of apparatus which, by electro-magnetic induction, transforms alternating electric power in one circuit into alternating electric power in another circuit, usually at a different value of voltage or current. Their broad classifications are, therefore, voltage transformers and current transformers. When, in the case of a voltage transformer, the voltage in the second circuit is higher than that in the first, the transformer is called a step-up transformer ; when the voltage in the second circuit is lower than that in the first, a step-down transformer is connoted. Similarly, a current transformer gives a higher current or a lower current. Transformation is usually effected at a constant frequency.

The essential parts of a transformer are the primary winding, the secondary winding, and the core. The primary winding is that to which the voltage is applied, while the secondary winding is that in which voltage is induced electromagnetically as a result of the magnetic flux established by the magneto-motive force of the primary winding.

Other parts which are non-essentials as far as transformer action is concerned, but which are essentials from a practical standpoint, are winding and core supports and bracing structure, terminals, tank, oil and auxiliary fittings, such as tapping links or switch, oil conservator, breather, cable boxes, rollers and various tank fittings.

Transformers can be designed for any number of phases, but in practice the more usual ones are single-phase, two-phase, three-phase and six-phase. The connexions for the different numbers of phases will be referred to later.

OUTLINE OF TRANSFORMER THEORY

In commercial practice almost all transformers possess a magnetic core, and in what now follows such construction is deemed to be the standard.

If the primary winding of a transformer is connected to a source of alternating E.M.F. with the secondary winding open-circuited, a small current, called the no-load current, flows in the primary winding, and this provides the necessary magnetization to the iron core and supplies the iron loss of the transformer. The primary no-load current multiplied by the primary turns gives the primary no-load magneto-motive force which sets up a certain alternating magnetic flux in the core, this inducing a back E.M.F. in the primary winding, and also an E.M.F. in the secondary winding. The magnetic flux is common to both primary and secondary windings, so that the voltages induced therein are in direct proportion to the respective number of turns. From this follows the standard voltage formula :

$$E = 4fn\Phi T$$

where E = R.M.S. value of the induced E.M.F. in the winding considered.
f = form factor of the E.M.F. wave (1·11 for sine wave).
frequency of the supply in cycles per second.
Φ = total magnetic flux through the core.
T number of turns in the winding considered

Losses. The vector diagram for a single-phase transformer on no-load is given in Fig. 1. On no-load the only losses which are of practical importance are the iron losses. The copper losses, due to the small no-load current, are generally ignored, as also are dielectric losses, except in large, extra-high voltage transformers.

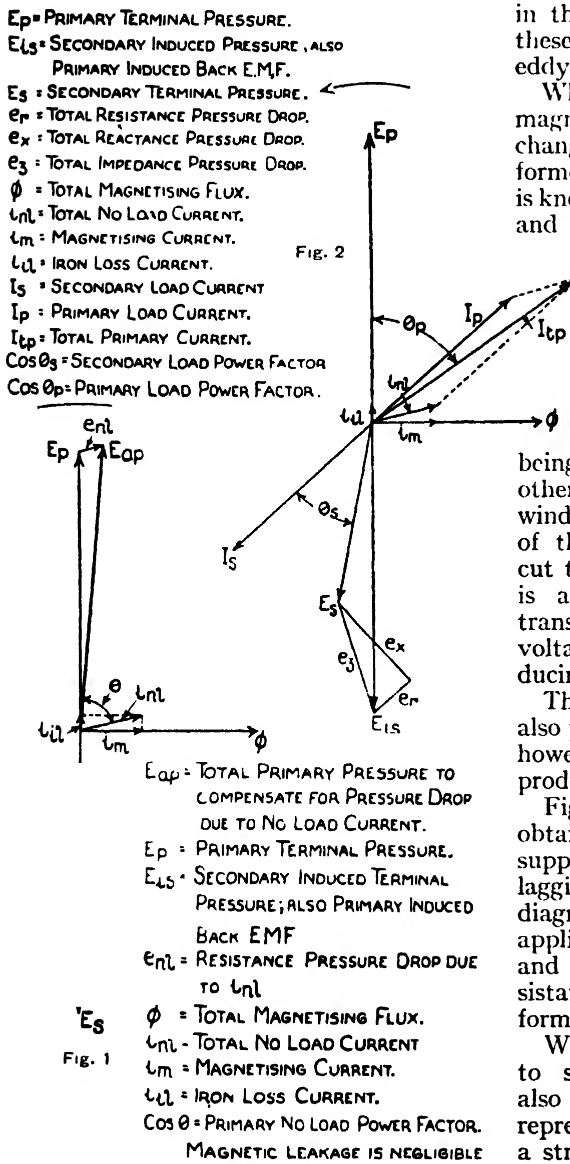
The average power factor of a transformer on open circuit is about 15 per cent., or 0·15.

When the secondary circuit is closed

through a load, a current flows therein, so that

$$I_s = \frac{E_{is}}{Z_s}$$ where Z_s is the impedance of the secondary load circuit.

This secondary load current is counterbalanced by a primary load current, so that primary and secondary load ampère turns are equal; and, being opposite in time phase, they do not affect the initial core magnetization corresponding to the no-load condition. This explains why the iron loss is independent of the load. The total current in the primary winding is the vector sum of the load and no-load currents.



TRANSFORMER. Fig. 1. Vector diagram for a single-phase transformer on no-load. Fig. 2. Supplying an inductive load of lagging power factor, cos θ. The pressure drop is transferred to secondary side.

The losses in the transformer are now increased by reason of the copper losses in the primary and secondary windings, these losses consisting of I^2R losses and of eddy current losses in the conductors.

While load fluxes do not affect the core magnetization, they do exert certain changes in the performance of a transformer, due to the phenomenon of what is known as leakage reactance. If primary and secondary windings could occupy exactly the same position, there could be no leakage of load flux between them, but as obviously this is a physical impossibility, a certain amount of load flux finds a return path in the space between the two windings. This flux is the leakage reactance flux, part being due to one winding and part to the other. The result is that with each winding we get a certain small portion of the total load flux which does not cut the other winding, and the net result is an internal loss of voltage in the transformer. In time phase this reactance voltage is 90° behind the current producing it.

The resistances of the two windings also produce internal voltage drops which, however, are in phase with the currents producing them.

Fig. 2 shows vectorially the conditions obtaining in single-phase transformers supplying an inductive load having a lagging power factor cos θ_s. In this diagram it is assumed that the primary applied voltage is maintained constant and that the whole of the internal resistance and reactance drop of the transformer is referred to the secondary side.

While Figs. 1 and 2 apply specifically to single-phase transformers, they can also be regarded with equal accuracy to represent the conditions in one phase of a straight polyphase transformer.

Outputs. The outputs of single-phase and three-phase transformers are given by the following equations.

Single-phase transformers—

$$\text{kVA} = \frac{4.44\, n\, \Phi T I}{10^8 \times 1{,}000}$$

Three-phase transformers—

$$\text{kVA} = \frac{4.44\, n\, \Phi T I \times 1.73}{10^8 \times 1{,}000}$$

In the foregoing I is the full load line current.

The percentage regulation or voltage drop which occurs at the secondary terminals of the transformer supplying a load is

$$R \cos\theta + X \sin\theta + \frac{(X \cos\theta - R \sin\theta)^2}{200}$$

in which R = percentage resistance drop
X = percentage reactance drop
θ = angle of lag of load current.

The percentage resistance drop is

$$\frac{\text{Copper loss} \times 100}{\text{output}}$$

The reactance X may be obtained by calculation (details of which would be out of place in this work), or from tested impedance and resistance of the windings. In the latter case we get

$$X = \sqrt{Z^2 - R^2}$$

where Z = percentage impedance voltage drop.

Efficiency. It has been seen that the losses in a transformer are principally iron losses (at no-load) and copper losses (under load). From a knowledge of the losses the percentage efficiency of a transformer is obtained by the expression

$$\frac{(\text{Output in watts}) \times 100}{\text{Output in watts} + \text{total losses in watts}}$$

The load at which, in any transformer, the efficiency is the highest, is that given by the expression

$$\sqrt{\frac{\text{Iron Loss}}{\text{Copper Loss}}}$$

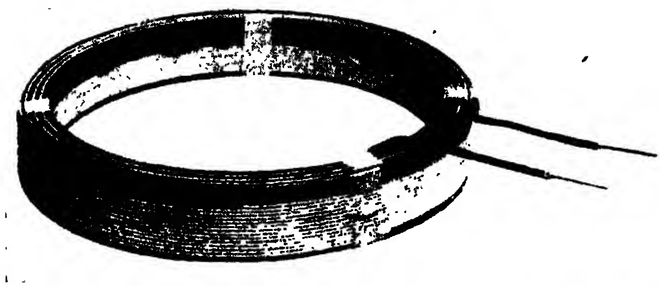
Harmonics in Transformers. Due to the fact that permeability of the magnetic circuit is not constant, odd harmonics of flux, current or voltage are usually present in commercial transformers, as these are designed for induction densities usually of the order of 13,500 lines per sq. cm. The harmonics range from the third upwards, and of these the third and the fifth generally are important only. Where the connexions permit, the no-load current contains the third harmonic and odd multiples thereof. Where the connexions do not allow the third harmonic to be present in the no-load current, it appears in the flux and induced voltage waves. Single-phase transformers, therefore, contain harmonics in the no-load current wave.

Three-phase star/star-connected transformers contain third harmonics in the flux and voltage to neutral waves if there is no fourth wire from the neutral on the primary side; if a fourth wire is present third harmonic currents flow in the windings and return to the source through the neutral wire, and these harmonics are then present in the current waves. With delta-connected windings third harmonic currents circulate in the delta but not in the supply lines. Higher harmonics are of quite small magnitudes in three-phase core type transformers, but they are large in three-phase shell type transformers or in three-phase groups of single-phase transformers. With core type transformers the third harmonic voltage per phase usually is between 1 per cent. and 5 per cent. With three-phase shell type transformers or groups of single-phase transformers, the third harmonic voltage per phase may be as high as 50 per cent of the fundamental (*see further under* Three-Phase).

The principal objection to these harmonic voltages is the additional dielectric stresses they produce on the transformer insulation and the possibility of their creating inductive interference to communication lines which may parallel the power lines to which the transformers may be connected. The general remedy is either to use a delta winding on the primary or secondary side (usually the former), or to design the magnetic circuit for an induction density not exceeding about 11,500 lines per sq. cm.

Transformer Construction and Connexions

Types of Power Transformers. Transformers for power and lighting and, in fact, for many other purposes, fall broadly into two classes: 1. Core type transformers; 2. Shell type transformers. In the former the windings encircle the cores, while in the latter the reverse is the case. Both types may have circular or rectangular coils, but the most common construction is circular coils for core type



TRANSFORMER. Fig. 3 (a). Cross-over coil winding bringing leads out at same level.

transformers and rectangular coils for shell type.

In core type transformers the cores are first assembled completely without the top yoke (except in very small air-insulated units) and the coils are then slipped over the individual cores, after which the top yoke is laced into position.

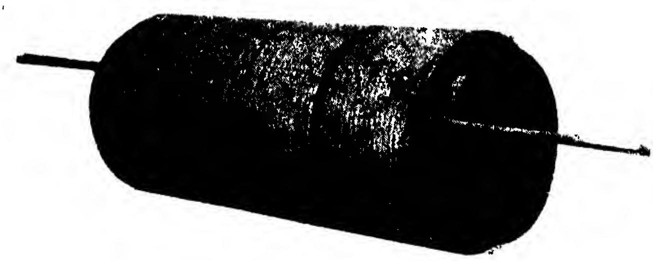


Fig. 3 (c). Spiral coil with leads at opposite ends.
Johnson & Phillips, Ltd.

In shell type units, however, the coils, together with all their insulation, are first stacked in position and the core plates are then assembled round the coils layer by layer. (*See* Fig. 6.)

Fig. 3 shows at *a*, *b* and *c* the three types of coils commonly used for core type transformers, while Fig. 4 shows the core and coils during assembly.

In all these coils the individual conductors may be insulated with paper or cotton and the insulation between adjacent turns may be reinforced with paper, empire cloth or press-spahn strips or with linen tape. All windings are dried and varnish impregnated under vacuum in order to remove all possible traces of moisture. The coils may be fitted with tappings as may be required for voltage adjustment.

Core plates of both types of transformers are usually 14 mils. thick and made of silicon steel sheet containing from $3\frac{1}{2}$ per cent. to 4 per cent. silicon. An alloy steel of this kind results in sheets having the requisite high resistance, high permeability and low losses which are so necessary for modern transformer construction.

Fig. 3 (b). "Section" coil bringing leads out at different levels.
Johnson & Phillips, Ltd.

Core plates are, of course, insulated on one side to prevent undue eddy current losses in the plate core structure.

Typical core and shell type transformers are shown in Figs. 5 and 6 in the next page.

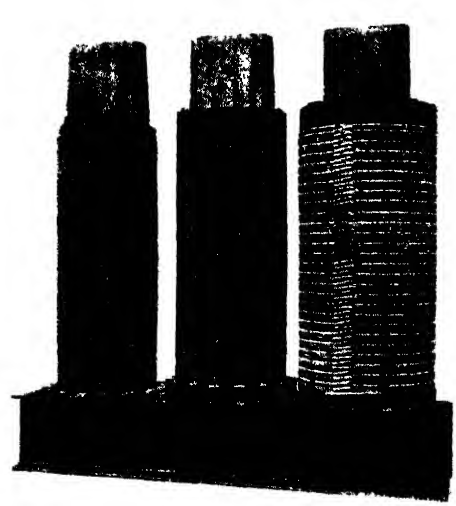
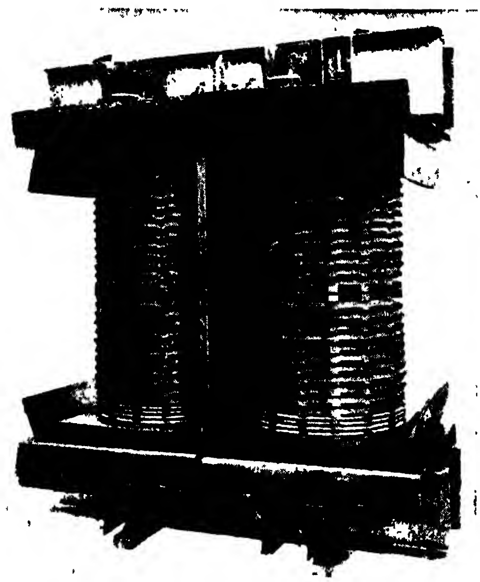


Fig. 4. H.T. side of 5,000 kVA transformer, in process of assembly, showing three stages of construction and core and coils.
Brush Electrical Engineering Co., Ltd.



TRANSFORMER. Fig. 5. Core type transformer during assembly showing coils and insulating spacers
Metropolitan-Vickers Electrical Co., Ltd.

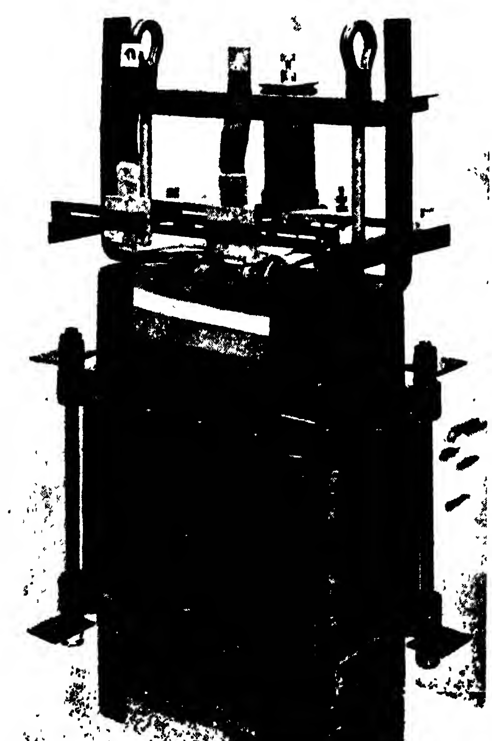


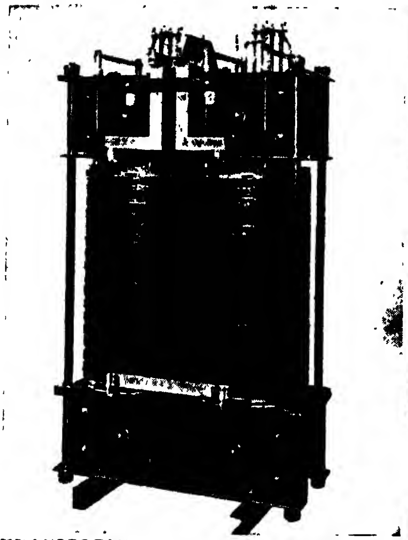
Fig. 6. Shell type transformer during assembly The laminated construction is clearly shown.
Metropolitan-Vickers Electrical Co., Ltd.

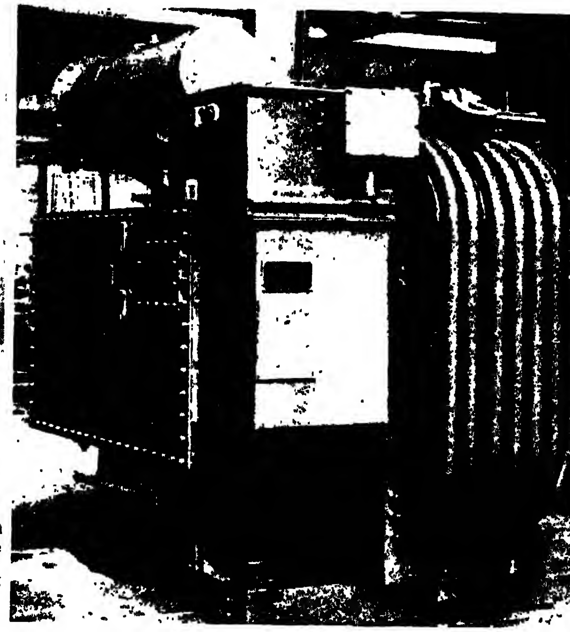
Types of Instrument Transformers. Instrument transformers, both shunt and series, adopt both the core and shell type construction which have been illustrated for power transformers. In addition, however, certain series transformers for use in connexion with discriminative protective schemes (*i.e.* Merz-Price, etc.) employ a circular form of core over which a secondary winding is wound in a distributed fashion. The primary, in such cases, often consists of a cable core threaded through the centre of the laminated iron ring, or of a bar or stud type primary.

Other Forms of Construction. For extremely high-frequency work transformers having air cores have been used, as, due to skin effect at very high frequency, the iron core would become most inefficient. A notable example of this form of construction is the Tesla transformer which was used very many years ago in the U.S.A. for producing extremely high-frequency, high-voltage discharges. *See also* High-Frequency Furnace; Northrup Furnace ; *etc.*

Tap-Changing Transformers. It is customary to fit voltage adjusting tappings to transformer windings usually on the H.T. side, these being required for varying the voltage of the transmission or distribution system according to system load requirements. On small transformers, tappings may be brought up to oil level and changed by means of plugs or links after the transformer has first been disconnected entirely from the supply. This entails interruption to supply, which, although permissible in certain instances, is always undesirable. The next alternative is to change the tappings, still with the transformer disconnected from the supply, but by means of externally operated tapping switches. This avoids the necessity for removing the tank cover and in the case of conservator type transformers of removing oil from the main tank. This practice is confined, however, to the smaller transformers or to the larger transformers where tap changing is required infrequently. (*See* Figs. 16 & 17.)

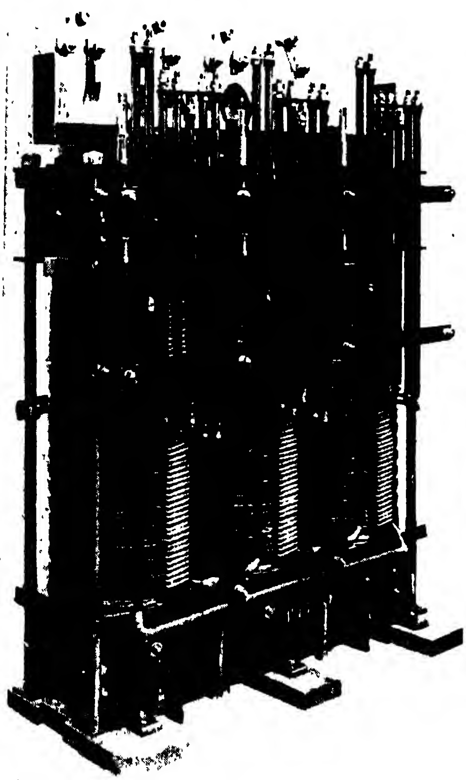
On-Load Tap-Changing. On larger transformers, such, for instance, as those on the "Grid" system, tap-changing is of frequent occurrence, and such trans-





TRANSFORMER. Fig. 7. Single-phase core type transformer with "section" H.T. winding. Fig. 8 (right). On-load tap-changing transformer and voltage regulator.

Johnson & Phillips, Ltd., and Hackbridge Electric Construction Co., Ltd.



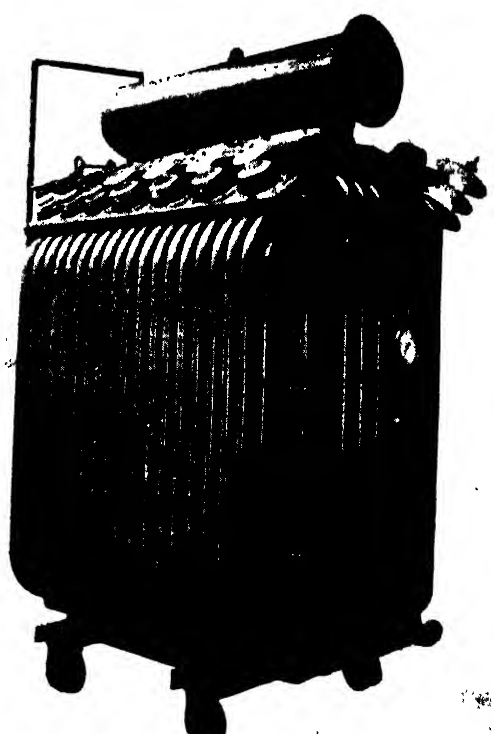
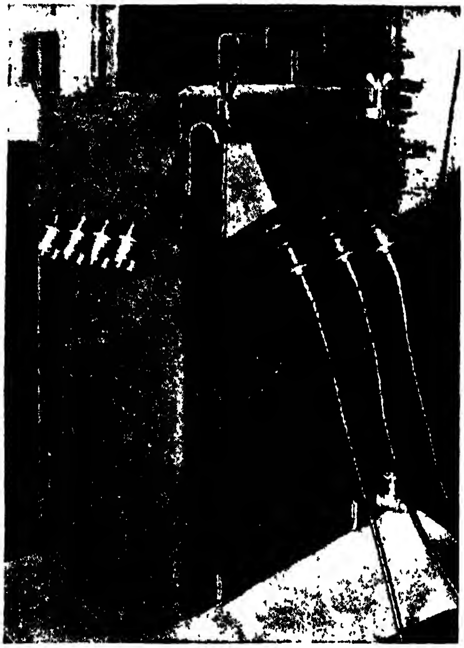


Fig. 9 (left). Three-phase core type power transformer. Fig. 10 (right). Three-phase outdoor transformer with conservator, breather, dial thermometer and rollers.

Johnson & Phillips, Ltd.



TRANSFORMER. Fig. 11. Three-phase outdoor transformer for pole-mounted equipment.
Johnson & Phillips, Ltd

formers are fitted with on-load tap-changing equipments. These may be operated manually or automatically. In one system the winding on each phase is split up into two equal parallel paths which normally share the load equally. Tappings are changed by permitting half of the winding to carry the whole of the load, while the tappings are being changed in the other half, and then the operation is repeated for the other half of the winding.

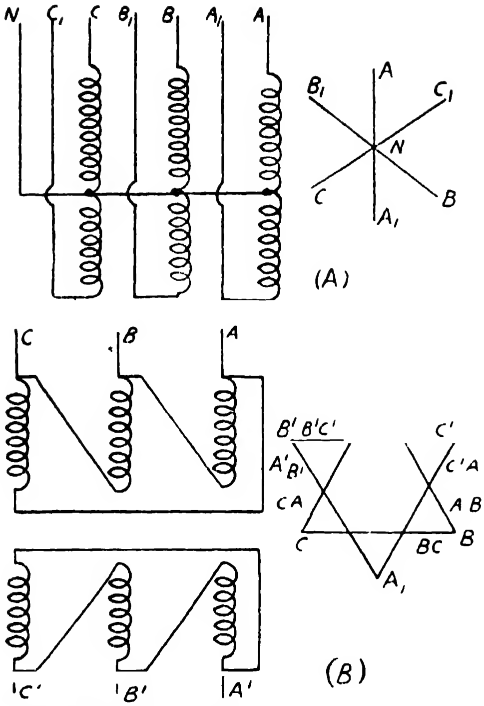
In another type of gear the winding in each phase is split, the two parts being normally in series. When tappings are to be changed a choke coil bridges the tappings which would otherwise be short-circuited when moving from one tap to another. The different on-load tap-changing equipments are far too elaborate to describe here, but Figs. 15 and 18 illustrate some typical arrangements. The interested reader is referred to "Voltage Regulation on A.C. Systems," by J. L. Rowbotham and T. F. Altham, published by the Hackbridge Electric Construction Co., Ltd., Walton-on-Thames.

Methods of Cooling. What one might call the standard type of transformer is naturally cooled, being either air insulated or oil insulated. The air-insulated type is more confined to the quite small units of a few kVA output, although sometimes transformers of hundreds of kVA output of this type are used in situations where increased fire risk due to leaking oil would be a dangerous hazard. Naturally cooled, air-insulated transformers are enclosed simply in an expanded metal or similar protective housing. Naturally cooled, oil-insulated transformers are built up to 5,000 kVA or more at 50 cycles, the voltage and frequency, of course, having a bearing upon what is the most economical proposition. Up to about 25 kVA they are contained in plain sheet iron tanks, and above this size either in substantial sheet iron tanks fitted with welded-in external cooling tubes or with detachable radiators constructed from round or oval section cooling tubes secured into headers. Tanks of this type carry each a number of separate radiators which, each being provided with oil valves, can be removed, if required, without disturbing the oil in the main tank and without interrupting the supply.

Still larger oil-insulated transformers, such as are found on the "Grid" system, employ a combination of natural and artificial cooling. In these, the oil-cooling radiators are entirely separate from the transformer tank, the oil being circulated through them by motor-driven pumps. Air-blast gear is also fitted to the radiators so that the transformer will give its maximum output as an air-blast cooled unit, and a lower normal output without the air blast.

Other types of cooling are (a) the water-cooled unit in which a water-cooling coil is placed inside the transformer tank in the uppermost part of the oil; (b) the forced oil-cooled transformer in which the oil is pumped through an external water-cooled or air-blast cooled oil cooler; and (c) the air-insulated, air-blast type in which cooling air is forced through the space between the coils and core and the outer protective casing.

Single-phase Connexions. So far as single-phase transformers operating as such are concerned, these are usually arranged on the secondary side for single-phase



TRANSFORMER. Fig. 12. (A) Double-star connexions. (B) Double-delta connexions.

two-wire, single-phase three-wire, or series-parallel connexion. In the first case, the transformer is a straight single-phase two-winding unit for which no unusual precautions have to be taken in the design. In the second case, unbalanced loads to neutral usually have to be catered for, so that the halves of the windings on either side of the secondary neutral must be interleaved, or alternatively the primary winding split up into two parts and paralleled. In the third case, the secondary winding is split into two equal parts so that they can be connected either in parallel for two-wire operation, or in series for three-wire operation; when connected in the latter manner the same precautions must be taken as outlined for the second case.

Polyphase Connexions. The connexions of polyphase transformers are much more numerous than those of single-phase transformers, and in this section we will deal with the more commonly used connexions. The different connexions which are available within this category are star, delta, and inter-connected star for three-phase transformers, with the addition of double-star and double-delta for six-phase connexions. In addition, we have, of course, the Scott connexion (*q.v.*) of transforming from two to three phase.

Primaries and/or secondary windings may have any of these connexions, but for straight three-phase transformation the usual connexion is delta/star for both step-up and step-down units. The star/star connexion enjoys a certain amount of popularity where loads are balanced and where no trouble is likely to arise from harmonics. For supplying six-phase rotary converters or rectifiers the double-star or double-delta secondary may be used with either a star or delta primary as required. Fig. 12 shows typical connexions.

In the case of the Scott connexion, two single-phase transformers generally are used, being connected on the three-phase side in the Tee manner and on the two-phase side either as two separate single-phase two-wire transformers, or as a two-phase three-wire group with a common neutral. (*See* diagram in page 1164.)

When the ratio of transformation, that is, of the higher voltage to the lower voltage, is low, economies in capital cost can usually be effected by the use of auto-transformers (*q.v.*). In these there is a single winding either the whole of which is connected with the primary circuit and part of which is connected to the secondary circuit, or *vice versa*. The method of voltage tapping for such an arrangement is shown in page 99. In most cases an auto-transformer (*q.v.*) is not a very favourable commercial proposition for transformation ratios above two.

Polyphase auto-transformers can be designed for star/star, delta/delta, star/inter-connected star, and inter-connected star/star connexions, as shown by Fig. 13.

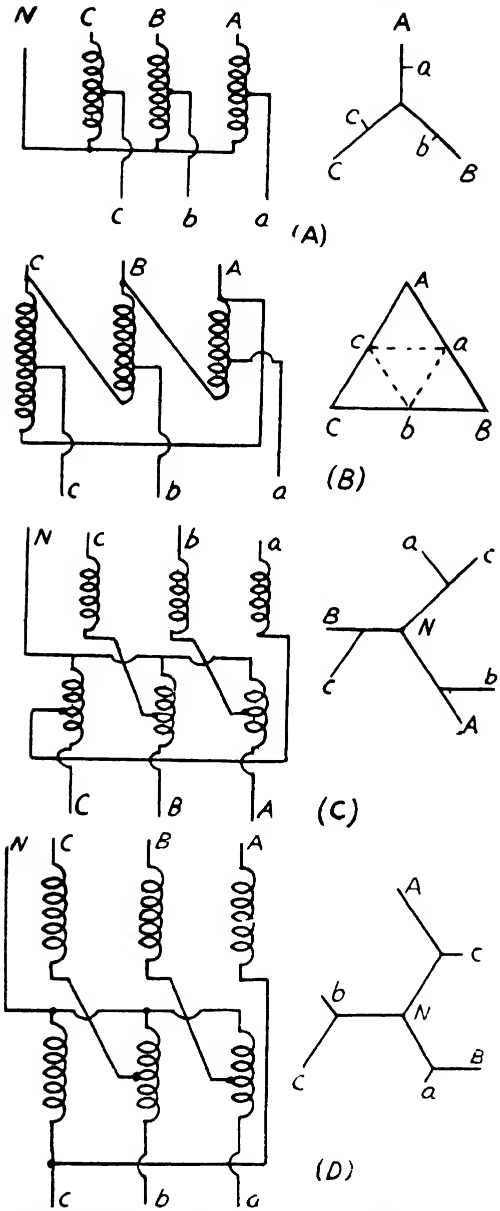
Parallel Operation. Certain requirements must be available before transformers can satisfactorily be operated in parallel on both primary and secondary sides. These requirements are as follows:

The transformers must have:

(1) The same angular displacement between primary and secondary voltages.
(2) The same voltage ratio
(3) The same percentage impedance
(4) The same polarity
(5) The same phase rotation.

The requirements (1) and (5) apply only to polyphase transformers. If voltage ratios are different it will be found when

paralleling two transformers that circulating currents flow in the windings which serve no useful purpose and only operate to reduce the useful load which can be supplied by the transformers. If the percentage impedances are different the respective transformers do not share the total load in proportion to their rated



TRANSFORMER. Fig. 13. (*A*) Star-star auto-transformer. (*B*) Delta-delta auto-transformer (*C*) Star-inter-connected star auto-transformer. (*D*) Inter-connected star-star auto-transformer.

outputs, the transformer with the lower percentage impedance taking the higher proportion of the total load, and *vice versa*.

The reference to polarity under item (4) above means that two or more transformers in parallel have the same polarity when their instantaneous terminal voltages are in phase. This obviously refers to both single and polyphase units.

As regards phase rotation, this is a characteristic of polyphase transformers only, and satisfactory parallel operation is achieved when the terminal voltages of the corresponding phases of the different transformers reach their maxima in the same order.

It has already been said that the angular displacement between primary and secondary terminal voltages is a characteristic only of polyphase transformers. For satisfactory parallel operation this requirement also separates the different transformer connexions into the following groups for three-phase units :

Group 1.	*Group* 2.
Star/star.	Star-delta.
Delta/delta.	Delta/star.
Delta/inter-connected star.	Inter-connected star/star.
	Star/inter-connected star.

Within each group any one connexion may be operated in parallel with any other connexion providing all the other requirements are complied with. It is not possible, however, to operate the connexion of one group in parallel with the connexion of the other group.

Tests, Installation and Maintenance

Factory Tests. The principal tests to which transformers are subjected in the factory before dispatch are for ratio, copper loss and impedance, iron loss and no-load current, pressure tests, and heat runs.

For the ratio test the transformer under test is balanced against a variable ratio standard transformer, and when no current flows in the secondary windings of the two transformers their ratios are the same. The particular ratio of the standard transformer is known for any given setting of the tapping switches controlling the secondary voltage, and this gives the ratio of the transformer under test. The test can be made with any convenient

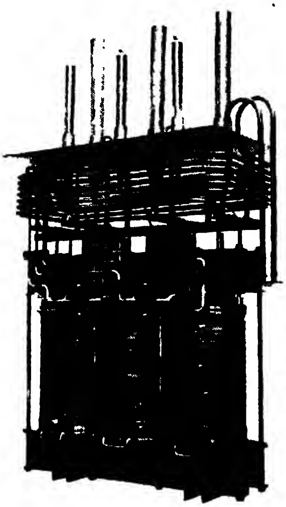


Fig 14 Three-phase core transformer, water-cooled, with condenser-type H T. terminals.

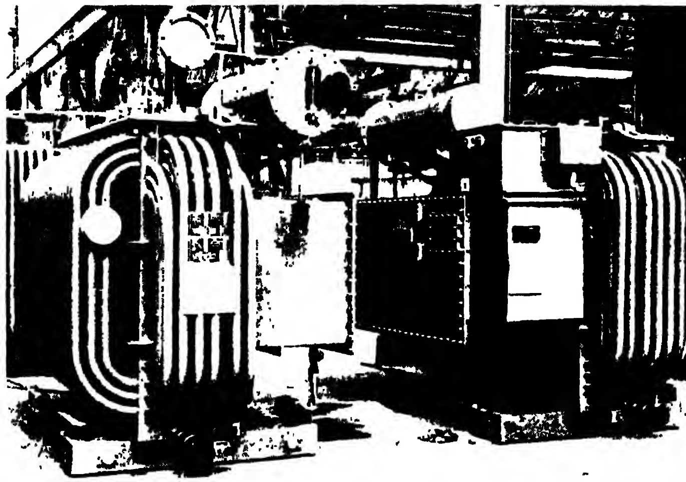


Fig 15 360-kVA regulating transformer, fitted with tapped resistance, on-load tap-changing equipment, arranged for motor operation

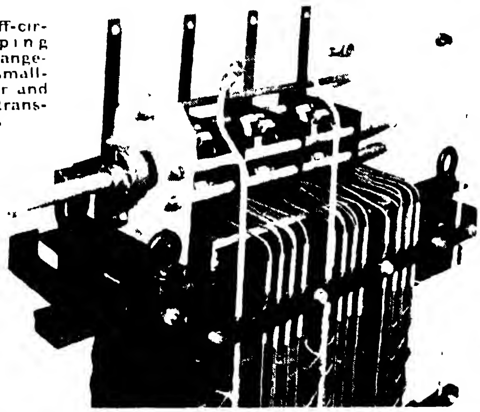


Fig 16 Off-circuit tapping switch arrangement for small-power indoor and outdoor transformers

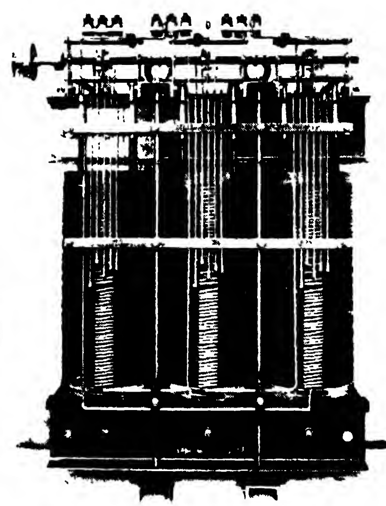


Fig 17 (right) Three-phase core type power transformer with off-circuit tapping switch

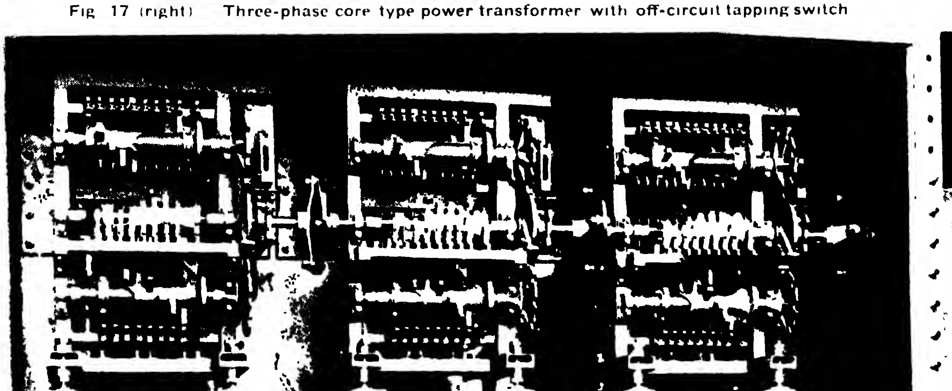
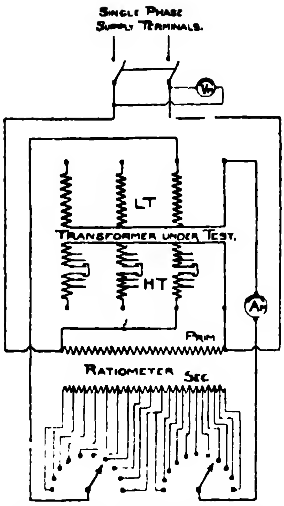


Fig. 18 Close-up of tapped choke coil tap-changing equipment on a 7,000-kVA 3-phase 33 66-kV transformer.

TRANSFORMER: REGULATING AND TAP-CHANGING EQUIPMENT

Photographs by courtesy of Johnson & Phillips, Ltd, and the Hackbridge Electric Construction Co, Ltd

To face page 1320



TRANSFORMER. Fig. 19 Diagram of connexions for ratio test of transformer by comparison with standard variable ratio transformer.

value of low voltage. The diagram of connexions is shown in Fig. 19.

The copper loss and impedance test is made by short-circuiting one winding and applying a low voltage to the other winding. The applied voltage is of such a value as to circulate full load current in the windings. The connexions for the test under single-phase transformer conditions are shown in Fig. 20, and in this the ammeter indicates the full load current, the voltmeter the impedance voltage, and the wattmeter the copper loss. The arrangement is similar for three-phase transformers in which ammeter, voltmeter and wattmeter readings are taken first in one phase and then in a second phase, adopting the two-wattmeter method of measurement. The total copper loss is then the algebraic sum of the two wattmeter readings.

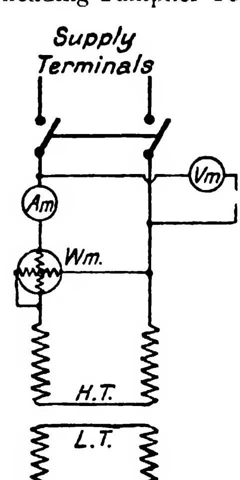
The iron loss and no-load current test is made by applying the full rated voltage to the terminals of one winding of the transformer with the other winding open-circuited. The diagram of connexions for the test is shown typically in Fig. 21, in which the ammeter reads the no-load current, the voltmeter the applied voltage, and the wattmeter the total iron loss. For three-phase transformers, readings are taken in two phases, adopting the two-wattmeter method as outlined for the copper loss test. The total iron loss is the algebraic sum of the two wattmeter readings.

Pressure Tests. These are of two kinds, the one testing the major insulation to earth and between windings, the other the minor interturn insulation. The first-mentioned test, termed " the flash test," is made on each winding separately with the other winding, and the core and the tank earthed. All the free ends of the winding under test are connected to one terminal of a high-voltage testing transformer, the other terminal of which is earthed. The testing voltage is usually raised to a value equal to twice the normal working voltage of the winding under test, plus 1,000 volts. This test voltage is maintained for one minute.

The second test, called " the over potential test," consists of applying a voltage difference between terminals of one winding with the other winding open-circuited for one minute equal to twice the normal rated voltage of the winding, plus 1,000 volts. The connexions of the test are practically the same as that shown in Fig. 21 for the iron loss test. The test is carried out at a frequency from 50 to 100 per cent. above that for which the transformer is designed, in order to avoid excessive no-load currents.

Pressure tests are carried out with the transformer in its tank of oil.

Heat runs are carried out usually by the short-circuit method or the back-to-back method. For the short circuit run, connexions are generally similar to those shown in Fig. 20 for the copper loss test, except that the total input to the transformer is equal to the sum of the iron and copper losses. In the case of the back to back run, this is described under the heading Sumpner Test.



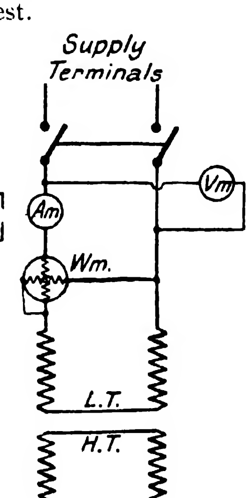
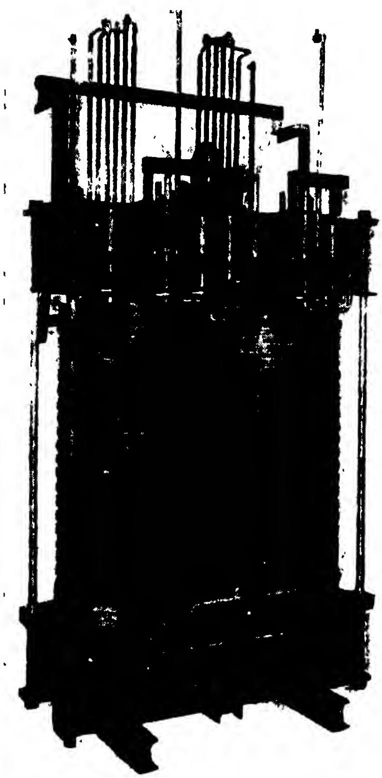


Fig. 20 (left). Copper loss and impedance test connexions for single-phase transformer. Fig. 21 (right). Iron loss and no-load current test connexions.

Installation. The majority of transformers nowadays are despatched in oil and therefore all that remains to be done is to top up with oil on site and connect up. It is desirable to leave the transformer on no-load for some time so that it may be warmed up by the iron losses. If the transformer has to parallel with another it should be phased in before making final connexions.

Indoor type transformers should always be accommodated in well-ventilated chambers which afford protection against rain, sleet, etc. The chambers should be ventilated and lighted adequately for obvious reasons. Where several transformers are accommodated in one chamber there should be approximately 3 ft. clear space between any two, and 2½ ft. between any transformer and an adjacent wall. In the case of outdoor transformers, whether pole-mounted or located at ground level, the same procedure should be adopted, but special care taken to see that all cover and similar joints are oil and water-tight.



TRANSFORMER. Fig. 22 Two-limb magnetic circuit, both limbs carrying primary and secondary windings of a single-phase transformer

Johnson & Phillips, Ltd

Maintenance. As regards maintenance, transformers should be lifted from their tanks and examined once in six or twelve months for the initial three or four years of their life. All slack nuts and bolts should be tightened and attention should be given to the screws of adjustable coil supports to see if it is necessary to take up any coil insulation shrinkage. Insulated bolts or core laminations should be meggered and the same procedure might usefully be adopted for the windings.

A sample of the oil should be taken from the bottom of the tank and tested for dielectric strength. The test between ½-in. diameter spheres should give a value not less than 20,000 volts across an 0·15-in. gap. If sludge has been deposited the oil should be run off from the transformer and filtered and the tank itself thoroughly cleaned out. Any moisture which has collected at the bottom of conservator vessels should be drawn off periodically. Clean, dry oil should always be introduced as make-up for any wet oil removed. If breathers are fitted the drying agent should be replenished fairly frequently. Insulators should be cleaned down periodically with a dry cloth. It is important to earth all exposed non-current-carrying metal in a positive manner.

Transformer Breakdowns. Transformer failures, though rare, may occur in the magnetic, electric and dielectric circuits. Failures in the magnetic circuit are associated with the breakdown of the insulation around core and yoke clamping bolts, and the subsequent heating is greatest when two bolts break down simultaneously, forming a short-circuited turn round the main flux. Failure of insulation between laminations produces large eddy currents which may damage the core and coil insulation.

Failures in the electric circuit are more frequently due to interturn insulation breakdowns which may be occasioned by switching setting up high voltage gradients in the windings as well as possibly high electro-magnetic stresses. Breakdowns of this kind usually lead to burning out a portion of the faulty winding before the transformer becomes disconnected from the supply. External short circuits are sometimes responsible for a severe disruption of the winding conductors due to the intense electro-magnetic stresses set up in the windings.

Failures in the dielectric circuit may occur due to the presence of moisture in the oil, to abnormally high temperatures arising from severe overloads, and due to system faults which result in injecting transient high voltages into the transformer.

Among the miscellaneous breakdowns to which transformers are sometimes subjected are the following:

Distortion of terminal leads under short circuit, due to insufficient bracing.

Leaking tanks due to porous welding or spongy plates.

Flashing over of insulators due to surface contamination.

Excessive temperature rise and coil insulation deterioration due to placing transformers too near to each other, or to chamber walls.

Flux harmonic amplification due to line capacitance.

Transformer Oil. The basic requirements in respect of insulating oil for transformers are laid down in the British Standards Institution Specification, B.S.S. 148–1933, and reference should be made to this document which also gives details of the tests which should be made. The matter is more fully considered under the heading Oil, Insulating, page 890.

Miscellaneous Applications. Apart from the use of transformers for the straight transformation of electric power on transmission and distribution systems, they are used for a variety of other purposes, the principal of which may be cited as follows: Static boosters and regulators, high-voltage testing transformers, welding transformers, X-ray transformers, auto-balancers, isolating transformers, furnace transformers and earthing transformers.

Booster and regulating transformers are designed so that the primary winding is connected across the supply lines, while the secondary winding is connected in series with the line, the voltage of which is to be boosted and/or regulated. The voltage is regulated by means of tappings located on the primary winding, the tappings being controlled manually or automatically on load as may be desired. Alternatively the regulating and boosting transformers may be separate, in which case the primary of the regulating transformer is connected across the line, the secondary feeding the primary of the boosting transformer and the secondary of the latter being connected in series with the line. In this case the voltage tappings are placed on the regulating transformer secondary.

High voltage testing transformers are characterized usually by their relatively small output for the voltage for which they are built. They may be designed for voltages up to 1,000,000 either in a single unit or in several separate units which are connected in cascade. More commonly these transformers are oil insulated, but transformers are on the market for this class of service which are entirely air insulated. The major insulation between windings and to earth in these high voltage testing transformers takes up the major portion of the space occupied by the complete unit.

Welding transformers, X-ray and furnace transformers are considered in the articles concerned with these subjects.

Auto-balancers may be single-phase or three-phase, and are used for providing a neutral point to which unbalanced loads may be connected and by the medium of which voltage drops are minimized by the redistribution of currents in the lines on the supply side of the balancer. They are single-winding one-to-one transformers and usually are designed for relatively small outputs and low voltages.

Isolating transformers having a one-to-one ratio are sometimes used when it is desired to isolate one part of a circuit from another part of the same circuit without modifying the voltage and current of the two parts. If a one-to-one double-wound transformer be inserted in such a circuit, the two parts are electrically separated and, being linked electromagnetically, they function as a homogeneous circuit although separated electrically. The design of such transformers follows conventional practice.

Earthing transformers are used for deriving an artificial neutral point on a delta-connected system, and they are described elsewhere (*see* page 408).

Numerous transformer text-books are on the market and the interested reader who requires specialized knowledge of transformer engineering is recommended to study these. Some of the more important are listed in the next page.

"Transformers for Single and Multiphase Currents," by G Kapp, revised by R. O. Kapp. Pitmans (1925).
"The Essentials of Transformer Practice," by E. G. Reed. Chapman & Hall (1927)
"Transformer Construction and Operation," by E. G. Reed. McGraw-Hill (1928)
"Transformer Systems and Their Operation," by W. T. Taylor. Griffin & Co., Ltd. (1927).
"Electrical Transformer Theory," by S G Monk Pitmans (1933).
"The J. and P. Transformer Book," by S. A. Stigant and H. M Lacey. Johnson & Phillips, Ltd. (1925).

TRANSFORMER GENERATOR. A form of frequency changer (*q.v.*) of the induction motor type.

TRANSFORMER OIL. *See* Oil, Insulating.

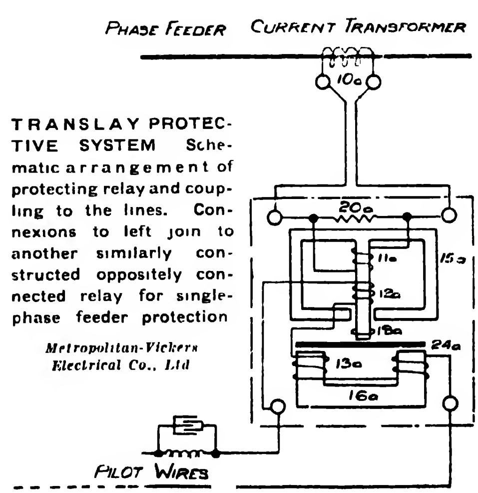
TRANSFORMER STATION. More usually called a static sub-station, this is a transmitting or distributing centre, where energy is received at a certain voltage and transmitted or distributed at another voltage. In the former case the receiving voltage usually is stepped up for transmission, while in the latter case the receiving voltage usually is stepped down for distribution purposes. The simplest form of transformer sub-station is perhaps the familiar outdoor pole type station consisting of a small weatherproof transformer with H.T. isolating switch and fuses or switch-fuses.

In another category we get the industrial type of enclosed brick or similar sub-station containing one or more transformers with H.T. and L.T. switchgear, often of the iron-clad or panel type, together with the necessary electrical indicating and recording instruments. Yet another form is that of the enclosed type of static sub-station associated with power stations, in which individual transformers with their own isolators are placed in their own chamber, the circuit breakers being housed adjacent thereto, also in their own chambers. *See also* Grid Scheme; Overhead Lines; Sub-station: Transformer, *etc.*

TRANSIENT CURRENTS. In a circuit where the reactance is high compared to the resistance, the alternating current lags behind the applied voltage by nearly 90°. If the circuit is initially closed at an instant when the voltage has such a value or phase position that normally the current would be passing through zero value, the latter would immediately take up the sine variation. If, however, the switch were closed at an instant when the voltage is near zero and the current nearly a maximum, the normal sine law is upset. The resistance in the circuit will tend to distort the sine wave of current until normal conditions have been reached. The resulting current curve may be resolved into two components, namely, a normal sine wave and a die-away logarithmic curve known as a transient.

Amongst other contributory causes to the production of transients in transmission circuits may be mentioned lightning disturbance, switching, resonance, arcing grounds, earths, sudden changes of load, etc., and the transient may take the form of a surge, oscillation, stationary or travelling wave. *See* Oscillation; Surge.

TRANSLAY PROTECTIVE SYSTEM. A system of protection, due to the Metropolitan-Vickers Co., which depends upon the balance of the secondary voltages induced in the auxiliary circuits of the relays. The word "Translay" indicates that the relays function also as transformers. Ordinary current transformers are used, and the secondary circuits of the relays are interconnected (*see* diagram). As the maximum possible secondary voltage cannot exceed about 100, the capacity currents in the pilots are small, and their effect is annulled by a special compensation method. A biassing device prevents



TRANSLAY PROTECTIVE SYSTEM Schematic arrangement of protecting relay and coupling to the lines. Connexions to left join to another similarly constructed oppositely connected relay for single-phase feeder protection

Metropolitan-Vickers Electrical Co., Ltd

operation of the relays by straight through short-circuit currents. Three-phase lines can be protected by two relays at each end, one being responsive to short-circuit faults, the other to earth leakage faults. *See* Protective Devices.

TRANSMISSION. There is no clear-cut line of demarcation between transmission and distribution, both terms being loosely used and the functions overlapping. Broadly speaking, however, transmission implies transference of energy in bulk from one point to another, without supply being given to individual consumers on route. Distribution, on the other hand, is more concerned with reticulation to consumers, covering both primary and secondary networks. With this differentiation a feeder within a distribution system is a " transmission " line; and sometimes the lower voltage transmission lines are tapped on route to supply individual consumers. These illustrate points of overlapping. The matter is further discussed under Distribution.

In general, distribution pressures do not exceed 22 or 33 kV, and since it is above 33 kV that new technical problems begin to become pronounced, it will be convenient to discuss transmission from the standpoint of pressures of 33 kV upwards.

A.C. Transmission. Virtually all transmission schemes are carried out with 3-phase A.C. That results from the development and economy of 3-phase generation, and the ease with which pressures can be stepped up and down by static transformers. Nevertheless the system is by no means ideal. New factors that begin to intrude as transmission pressures increase above 33 kV are :—corona loss on overhead lines and dielectric hysteresis in cables, resulting in increased energy losses over long distances; difficulties associated with voltage regulation and phase displacement, due to increased capacity and inductance and to the capacity currents being relatively large, compared with load currents; and the greater liability to surge troubles.

Cables. The normal type of 3-core belted cable has been used with some success at 33 kV, and single-core cables of normal construction up to 66 kV. A trouble that is increasingly liable to occur at such pressures is breakdown due to ionization. In service the cables expand and contract due to heat from the varying load currents, and it is difficult to be sure that the lead sheath will shrink back tightly on to the core on cooling. Where it does not, partial vacuum results beneath the sheath and within the core insulation. Any gas present will fill these voids, and under the condition of partial vacuum the critical ionization pressure is reduced. The working voltage may then be sufficiently high to initiate ionization, leading to breakdown.

Due to the above cause special types of cable have been developed for pressures of 33 kV and above, such as the Hochstadter, S.L. (single lead), and oil-filled types (*see* Cable, pages 174-75). The latter is the only type so far employed for pressures as high as 132 kV, while the former have been successfully employed up to 66 kV. Installations at the highest pressures generally utilize single-core cables. Owing to the greatly increased cost compared with overhead lines (maybe a seven-fold increase at 132 kV), cables are only utilized for E.H.T. transmission where special conditions (as bringing a grid line through a populous urban area) justify that course. (At 11 kV in rural distribution, cables may be used in preference to overhead lines as stated in pages 487–88, but here E.H.T. problems do not arise.)

Overhead Transmission Lines. With increase of operating pressure above 33 kV the insulators become the most important feature of overhead line design. Both because of their greatly increased cost, and because every insulator point is a potential source of weakness, the longest practicable spans are adopted. Lattice steel towers and steel-core aluminium conductors find favour because they permit long spans being used. Pin-type insulators have been used at 66 kV, but suspension-type insulators are commonly preferred because of their better mechanical and electrical characteristics.

Modern practice demands insulators with good electrostatic balance. That is, to secure a constant puncture to flash-over voltage ratio at all frequencies, so that the insulators will flash-over rather than puncture under conditions of high-frequency transients. To the same end

TRANSMISSION. Figs. 1 and 2. Two types of towers used in the "Grid" transmission scheme. Fig. 3. Tower for the River Roding crossing of the S.E. England scheme.

Courtesy Central Electricity Board and G.E.C., Ltd., of England.

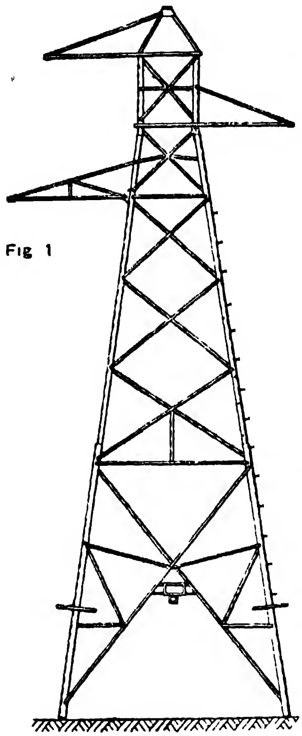


Fig 1

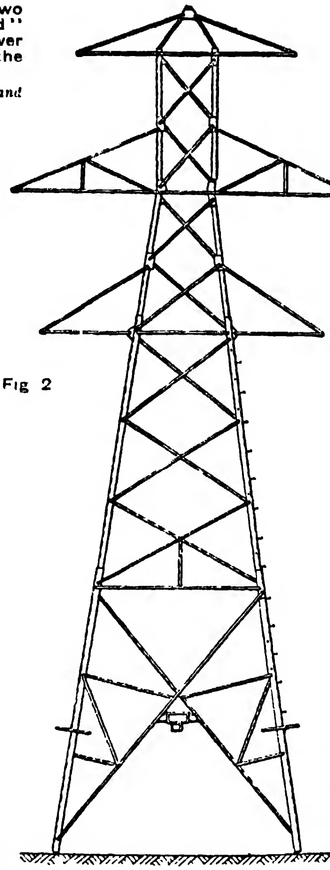
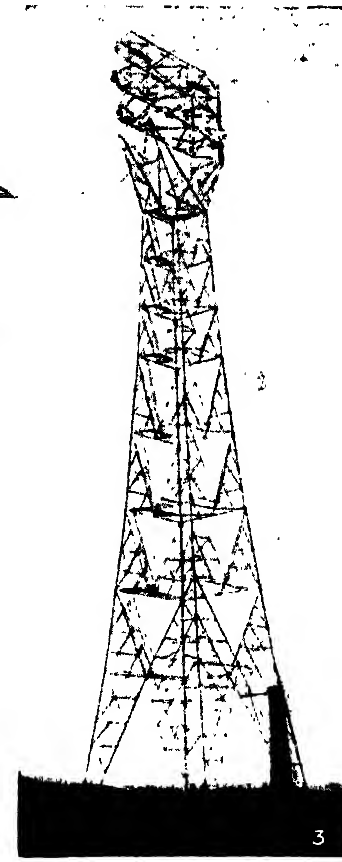


Fig 2



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grading rings are attached to the lowest insulator of a string, with arcing horns at the top, as on the "Grid" lines.

E.H.T. transmission lines are less subject to lightning troubles than lower voltage lines, as they have heavier insulation, while the induced voltages due to lightning are the same whatever the line operating voltage. Similar precautions against surges are taken as on lower voltage lines, *e.g.* extra insulation on end turns of transformers, generators, etc.

D.C. Transmission. Hitherto little headway has been made with direct-current transmission at extra high voltage. Practically the only instance is the Thury system (*q.v.*), of which the most notable installation operates at 50–60 kV. It is the opinion of many experts that from the purely transmission line aspect E.H.T. D.C. transmission has many potential advantages over A.C., including economy in first cost, operation and maintenance. The advantages are claimed to be increasingly pronounced the higher the pressure, 100 kV and over, and the greater the power to be transmitted, say 100,000 kW upwards. Hitherto, however, the insuperable difficulty has been to build suitable machines for generating E.H.T. D.C. at the sending station and corresponding equipment for stepping down the pressure at the receiving end. The main difficulty lies in commutation at extra high pressures.

Attempts have been made to develop D.C. transmission utilizing A.C. generation, notably the "Transverter" machine of Highfield and Calverley. This comprises A.C. transformers to step up the pressure and multiply the number of phases, in conjunction with a rotating commutator to convert to unidirectional D.C. for transmission, with corresponding reconversion equipment, D.C. to 3-phase A.C., at the receiving end.

Latterly, the advent of the grid-controlled, steel tank, mercury arc rectifier (*q.v.*) has again directed attention to the possibilities of D.C. transmission. These rectifiers are already extensively used for A.C. to D.C. conversion, notably for railway work, and their adaptability for inverted operation, D.C. to A.C., has further been demonstrated.

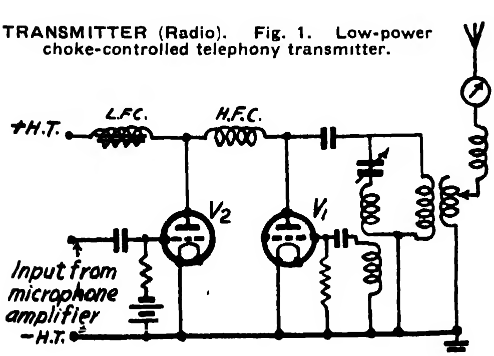
Another form of apparatus, the Marx rectifier (*q.v.*), may also prove to be of value for producing high-voltage D.C. from A.C.

The position, therefore, is that equipment is available that would make a working scale experiment in D.C. transmission practicable, and it is possible that it will be tried out on a practical scale. Nevertheless, it must not be overlooked that many associated problems remain to be solved, such as switching, voltage regulation, and interconnexion if two or more D.C. lines are to be linked together; and last, but by no means least, E.H.T. D.C. metering. *See* Cable Distribution; Feeder; "Grid" System; Network; Overhead Lines, *etc.*

TRANSMITTER (Radio). A radio transmitter consists of apparatus for generating high-frequency oscillations, modulating them according to the intelligence to be broadcast and feeding them into a radiating aerial system (*see* Broadcasting). In modern transmitters the high-frequency oscillations are generated by thermionic valves, although spark transmission is still used for maritime communication.

There are very many circuit systems possible and choice is made to suit the power involved, the wavelength and other conditions. A simple transmitting circuit for low-power telephony is shown in Fig. 1 where choke-control modulation (*q.v.*) is used. V_1 is the oscillator valve, which is parallel fed and whose output circuit is inductively coupled to the aerial. V_2 is the modulator valve with L.F. choke in the anode circuit. The valve anodes are joined through the high-frequency choke which prevents H.F. current from reaching the modulator stage.

TRANSMITTER (Radio). Fig. 1. Low-power choke-controlled telephony transmitter.



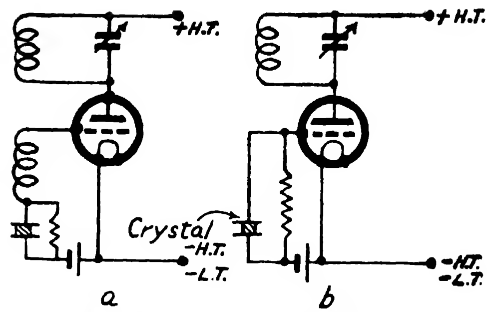
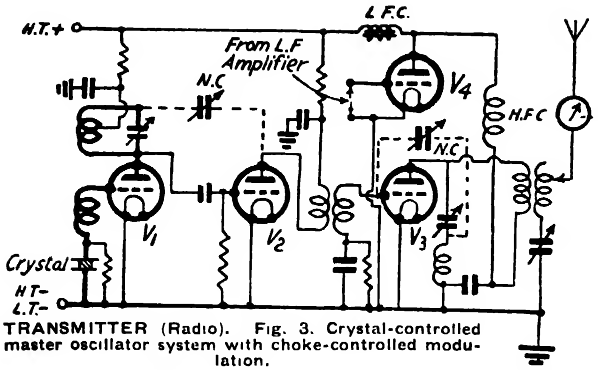


Fig. 2. Methods of quartz crystal control.

Master Oscillator System. The most generally used system for broadcasting transmitters is that in which a master valve-oscillator is made to generate the high-frequency oscillations at low power, these being subsequently amplified, modulated, and further amplified by a high-frequency power amplifier before being fed to the aerial system.

Owing to the large number of transmissions to be accommodated within the practical range of transmitting frequencies available, it is essential for each transmitter to operate at the frequency or wavelength allotted to it within a high limit of accuracy, and for this reason the frequency is usually crystal-controlled. A quartz crystal correctly cut and proportioned will maintain the frequency constant to a remarkable degree. Such a crystal has the peculiar property of being mechanically strained or distorted when a voltage is applied between opposite faces, and *vice versa*, the phenomenon being known as the Piezo-electric effect. Besides this, it is of a highly elastic nature and mechanical resonance occurs at a very sharply defined frequency.

There are two ways of applying quartz control to a valve oscillator, as shown at (*a*) and (*b*) in Fig. 2. In both cases the anode circuit is tuned to the natural frequency of the crystal, but in (*a*) a small



TRANSMITTER (Radio). Fig. 3. Crystal-controlled master oscillator system with choke-controlled modulation.

degree of inductive coupling is provided between grid and anode circuits, whereas in (*b*) the necessary coupling is only that afforded by the inter-electrode capacity (*q.v.*) between anode and grid. Without the crystal these couplings would be insufficient to produce self-oscillation. Temperature affects the crystal to some extent, and for this reason it is sometimes enclosed in a space where the temperature is kept constant by thermostatic control. In these circumstances the frequency of the oscillator can be controlled to 30 or 40 parts in a million. As the crystal is an insulator a grid leak resistance is necessary for applying grid-bias voltage.

Fig. 3 gives an example of a master oscillator system with crystal control and employing choke modulation. Neutralizing condensers NC are shown, these being necessary to prevent feed-back from later to earlier stages (*see* Neutrodyne). Where a large power output is required further stages of amplification follow the modulator stage. In all transmitters the output valve is loosely coupled to the aerial circuit, which is tuned, as there is an optimum coupling giving maximum aerial current, as indicated by the aerial ammeter. If the coupling is made tighter than that giving maximum current, two frequencies will be radiated, a double hump resonance curve being obtained as for a band-pass filter.

Power Supply. Transmitting valves are operated at high anode potential, being of the order of 10,000 volts in a broadcasting station, and the power plant required is of a highly specialized nature. The valves have directly heated filaments, and the low-tension current required is correspondingly high, and for the sake of hum-free operation of the transmitter storage batteries are widely used for the low-tension supply.

It is common practice in many instances to obtain the power for a broadcast transmitter from public supply mains, but in most cases an independent generating plant is installed as a stand-by to ensure continuity of the transmission in the event of failure of the outside supply. High-tension current can be obtained from valve or mercury arc rectifiers operating on A.C. supply, preferably three-phase. In some of the most recent broadcasting stations the whole of the electrical power required is generated locally, such a system having the advantages of economy and independence.

D.C. motor-generator sets are employed for supplying the H.T. and L.T. current. For the H.T. supply, special generators each with two armature windings and two commutators are used, two such machines being mechanically coupled and driven by a single motor. The four armature windings are joined in series so that only one-fourth of the total output voltage occurs across each commutator—2,500 volts for a 10,000-volt supply, the arrangement being shown in Fig. 4. The shunt-field windings of the generators are supplied from the 230-volt main supply, and owing to the constant nature of the load, automatic voltage regulation or compounding is unnecessary. In fact, it is an advantage to have reverse compounding or differential compounding to limit the current when a breakdown in the nature of a short circuit occurs.

On account of the high voltages used, all live parts have to be protected by earthed screens to prevent accidental contact by any person and all controls

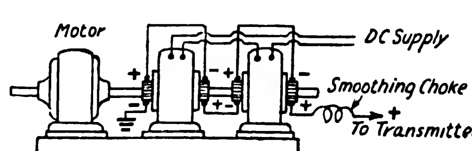


Fig. 4. A motor-generator set for supplying H.T. current at 10,000 to 12,000 volts.

must be mounted in such a way as to ensure safety.

The transmitter itself is usually divided into sections—for instance, the low-frequency amplifier, master oscillator, high-frequency amplifier, modulator stage, and power amplifier stage are built as separate units, each being enclosed behind earthed screens or grids.

The various stages and processes involved in a complete broadcasting transmitter from microphone to aerial are outlined under Broadcasting. *See also* Modulation ; Oscillator.

TRANSVERTER. In addition to the well-known rotary converter in which the voltage transformation is carried out by a separate transformer, the transverter has been developed which attacks the problem of A.C. to D.C. conversion, and *vice versa*, in a different way. This apparatus was developed by Messrs. J. E. Calverley and W. E. Highfield at the works of the English Electric Co., Ltd., and operates on the direct inversion of the ordinary D.C. revolving armature. The design consists essentially of a group of phase-multiplying transformers and a commutating group, in which synchronously driven brush-gear is rotated about the requisite number of fixed commutators. The brushes short-circuit the secondary coils that are at zero potential to achieve rectification.

The three-phase A.C. supply is phase-multiplied by special windings on the main transformers to produce thirty-six phases. Numerous similar secondary coils on the same eighteen limbs as the primaries are connected to the commutator bars in such a way that the voltage is built up progressively from one pole to the next. The revolving brushes short-circuit the secondaries to yield rectified direct current supply.

Such machines have not been extensively developed in commercial practice owing to the capital cost being much greater than a static transformer set of like output, and the extra maintenance and attendance charges involved. The advantages are the few moving parts required and the fact that the windings are stationary, and can therefore be immersed in oil. A standardized construction may be adopted for all the secondary windings, since they are identical. Against these are the disadvantages of the extra losses introduced by the commutators and the fact that the breakdown of one winding would throw the whole set out of action. *See also* Converter.

TRICKLE CHARGING. A term that has two implications. The first is one commonly and loosely used to describe the process of charging (*q.v.*) accumulators at lower rates than normal, whilst the other is a technically correct expression which describes charging specially designed to compensate for standing losses due to hydration.

Losses due to standing idle are very small, and amount to a small percentage of the capacity of the cells per month in the case of lead-acid batteries, and are practically non-existent with alkaline cells. Consequently, trickle charging designed to compensate for such losses need be but a very small percentage of normal charging rates. Approximately, one quarter ampère for every 1,000 ampère-hours capacity of the cells is sufficient for this purpose.

The more common definition of the term applies to any charging carried out at rates considerably below the normal. This is a procedure that is by no means beneficial to the cells, and should not be practised except in cases of necessity, where proper means of charging at normal rates do not exist. The only justification, otherwise, for low rate charging is when the cells are over-discharged and have become somewhat over-sulphated thereby. A low rate of charging is then beneficial. It would be better, in these cases, not to speak of trickle charging, because in this sense the term is too loosely applied.

The chief practical application of trickle charging is in connexion with emergency lighting (*q.v.*), where batteries are kept in a fully charged state when not in use by automatic switches closing to allow trickle rates until the batteries are fully charged, when they cut out again. *See also* Keepalite.

TRIFURCATING BOX. A dividing box in which the joints may be enclosed between a three-core or triple concentric cable and three single-core cables or bare

conductors. Wooden spreaders are inserted in such joint boxes to keep the three cores separate, and the joints for each core made as described under Joints and Jointing (*q.v.*). The box is then filled with compound in the usual manner. *See* Dividing Box ; Joint Box, *etc*.

TRIGONOMETRICAL FUNCTIONS. Trigonometry is a branch of mathematics dealing with the ratios of the sides of rectangular triangles. The trigonometrical functions express these ratios. Consider Fig. 1. ABC is a rectangular triangle. The right angle is at C. We can divide each of the three sides by the other two. This gives six possible ratios. They are the six trigonometrical functions, namely :

a/c =	sine α ..	. written sin α
b/c =	cosine α	. written cos α
a/b =	tangent α	. written tan α
c/a =	cosecant α	. written cosec α
c/b =	secant α	written sec α
b/a =	cotangent	written cot α

These functions have been calculated for all angles and their values are printed in mathematical tables. They provide quick means of finding the dimensions of rectangular triangles. If, for instance, the angle α and the length of side c are known, one can find a by looking up sin α in the tables and multiplying it by c. Similarly b is found as $c \times \cos \alpha$. Or if a and b are known, α can be found by looking up in a table the value for $a/b = \tan \alpha$.

Every triangle can be divided into two rectangular triangles by drawing a line from an apex perpendicular to the opposite side. Therefore the trigonometric functions can be adapted to express the measurements of any triangle. They are used in this way in surveying. One side of a triangle is measured on the ground, and the two angles to a selected point from each end of this line are measured. Tables of the trigonometrical functions make it possible to find the distances to the point from each end of the measured line without the need of going over the ground or even visiting the distant point.

This is only one use of the trigonometrical functions. They help to solve every problem in which the ratios of straight lines at an angle to each other are significant. Thus the effect of a number of forces acting in different directions can be conveniently represented on paper by straight lines. Their joint effect in magnitude and direction is best found by the use of tables of the trigonometrical functions. A simple instance is provided by a body sliding down a smooth inclined plane. Its tendency to slide depends on the steepness of the plane, that is to say on its angle. It can be shown that this tendency is proportional to the sine of the angle.

In electrical engineering the trigonometrical functions are used in a variety of ways. They are essential for the calculation of the forces acting on the various parts of machines and apparatus as in all engineering. They also have a special application in the calculation of the effect of combining currents and voltages in alternating current work. An alternating current or voltage follows a sine curve (*q.v.*). It can be represented by a line called a vector (*q.v.*). The lines representing other currents or voltages can be represented by other vectors differing in length and direction from the first. When such vectors are placed so as to form triangles, the values of unknown magnitude can be calculated from the known quantities with the help of the trigonometrical functions. A common and simple example is the calculation of the power of an alternating current. The vector for

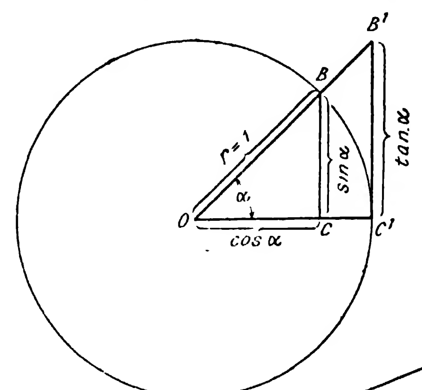
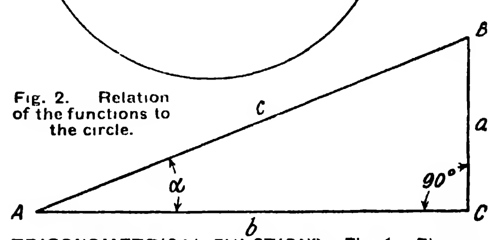
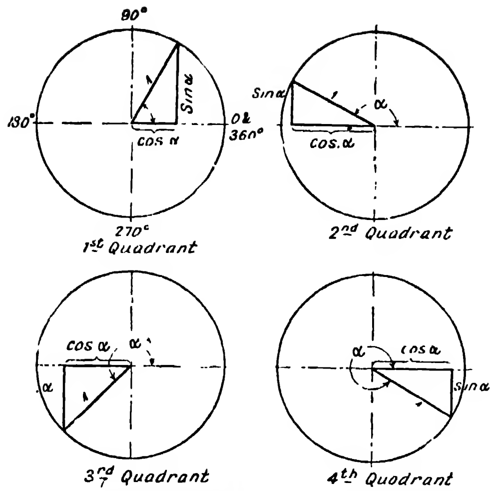


Fig. 2. Relation of the functions to the circle.



TRIGONOMETRICAL FUNCTIONS. Fig. 1. The rectangular triangle from which sine, cosine and tangent are derived.



TRIGONOMETRICAL FUNCTIONS. Fig. 3. The positive and negative signs of α between 0° and 360°.

the voltage makes an angle of ϕ with that for the associated current. It can be shown with the help of trigonometry that the power is $E \times I \times \cos\phi$, where E and I are respectively the voltage and the current.

Fig. 2 shows how the trigonometrical functions are related to the circle. If BC is at right angles to OC′, BC/OB = sin α. OB is the radius of the circle. If this is 1, BC is sin α, OC is cos α and C′B′ is tan α. It is evident that sin α and cos α are always less than 1 and that tan α may have any value.

Fig. 3 demonstrates the values which sin α and cos α assume for various values of α between 0° and 360°. The figure shows that four quadrants are distinguished. For the first, α is an acute angle. For the second it is an obtuse angle. It is between 90° and 180°. For the third, it is between 180° and 270°, and for the fourth between 270° and 360°. It is a convention that any values of sin α and cos α which are measured to the right of the centre of the circle and above it are called positive, and any to the left and below it are called negative. This gives the following table of signs of sin α and cos α.

	sin α	cos α
First quadrant ..	+	+
Second quadrant ..	+	−
Third quadrant ..	−	−
Fourth quadrant ..	−	+

Tan α is not shown in Fig. 3, but it will be easily understood that its sign is always the same as that of sin α. Cosecant, secant and cotangent are respectively one divided by sine, cosine and tangent, so that their signs correspond to these. *See* Cosine.

TRIODE. Another name for three-electrode valve. *See* Valve.

TRIP CIRCUIT. Various types of relays are available for the different protective systems and their applications. All, however, are alike in that they control the circuit including the winding of the electro-magnetic mechanism by whose action the circuit breaker is tripped.

This circuit is known as the trip circuit, and the relay either by rotation of a disc or the release of a detent closes a set of contacts which completes the trip circuit and brings the circuit-breaker release into operation. The relative position of the contacts can be altered to enable adjustment of the time of action of the relay according to requirements, and modern circuit breakers can be relied upon to open a circuit within about 0·25 second of the relay contacts closing. *See* Circuit Breaker; Protective Devices; Relays; Switchgear, *etc.*

TRIPLE FREQUENCY HARMONIC. Alternative name for Third Harmonic (*q.v.*).

TRIP RELAY. The relay by whose operation the trip circuit is closed, thereby causing the circuit breaker to open. Fully discussed under the heading Relays (*q.v.*).

TRIP SWITCH. In addition to the automatic operation of the circuit breaker on occurrence of fault, by the agency of various protective devices, relays and trip circuits, etc., means must also be provided for operating the trip circuit by hand. The apparatus is simple, consisting merely of the necessary small switch for closing the trip circuit. This switch may be situated on the remote control or main switchboard panel and an indicator lamp in series with it lights up when the circuit breaker is tripped. *See* Circuit Breaker; Remote Control; Switch, *etc.*

TRIVECTOR An integrating meter for measuring the reactive power, discussed under the heading Kilovolt-Ampère-Hour Meter.

THE TROLLEY-BUS & ITS EQUIPMENT

By A. T. Dover, M.I.E.E., A.Amer.I.E.E., Author of "Electric Traction"

Here is given a discussion on the operating features and advantages of trolley-buses, as compared with tramways and the ordinary omnibus, together with a sketch of the electrical equipment, the running and overhead construction. Reference should specially be made to the main article on Traction. The driving motors are dealt with under appropriate headings in other parts of the work.

The trolley-bus is becoming increasingly important as a public-service vehicle for passenger transport, as it combines the advantages of electric operation with the mobility of the internal-combustion-engined (I.C.E.) bus. The ability always to load and unload passengers from the kerb instead of the road is a factor of prime importance in any system of passenger transport, and it is this feature which has led to the tremendous increase in bus transport systems throughout the whole country. Moreover, the mobility of the bus is a valuable asset in relieving traffic congestion and in speeding up the transport system in towns with dense traffic and narrow thoroughfares.

Advantages of Trolley-Buses. The outstanding advantages of a trolley-bus are its quietness, smooth and vibrationless operation, and the absence of fumes and smell. Such features are possessed by no other road vehicle or road transport system.

Moreover, due to the trolley-bus receiving its energy from an external electric supply system, the energy which the vehicle can obtain during short periods is enormously greater than that which could be obtained from an internal supply system.

This feature, combined with the speed-torque and overload characteristics of the electric motor, enable very high acceleration—2·5 m.p.h. per second—to be obtained with a power unit of relatively low continuous rating compared with that for a practicable I.C.E. bus.

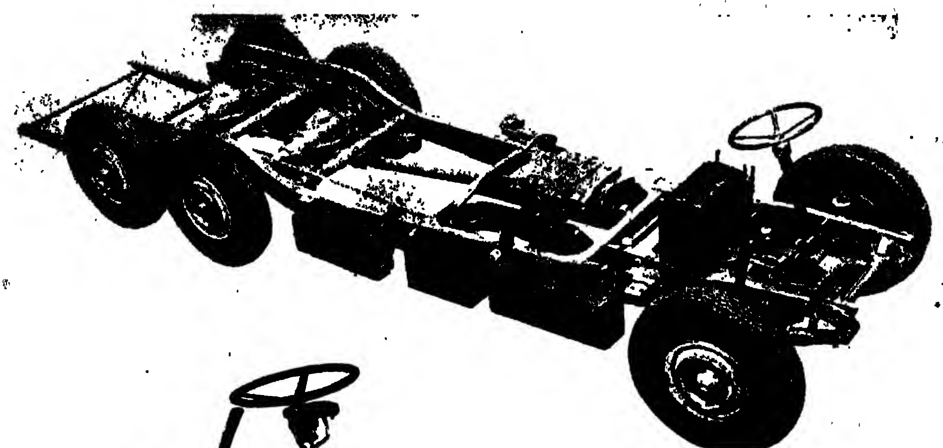
Further, the power equipment on a trolley-bus may also be used—in conjunction with power-operated wheel brakes—for braking the vehicle, and by these means a very high braking retardation ($2\frac{3}{4}$ to 3 m.p.h. per second) may be obtained. Thus, the trolley-bus is capable of giving a higher schedule speed than an I.C.E. bus of equal weight. Incidentally, the maximum speed of the former may actually be lower than that of the latter vehicle.

It is these features, together with those already mentioned, that are responsible for the rapid increase of popularity of the trolley-bus with the travelling public. One cannot conceive any other form of vehicle which, while giving the advantages of rapid transit, gives also the maximum comfort to the passengers.

Operating Advantages. The trolley-bus is much simpler to drive and manœuvre than an I.C.E. vehicle. This operation is, therefore, in the case of a trolley-bus, less fatiguing to the driver, who is thereby able to render better service in charge of the vehicle.

The maintenance of a trolley-bus is exceptionally low in comparison with that of an I.C.E. vehicle, the chief item of maintenance being tires. Costly renewals

TROLLEY-BUS. Fig. 1. General body design of a trolley-bus.
English Electric Co., Ltd.



TROLLEY-BUS. Fig. 2. View with body removed, showing lay-out of motor and transmission.
English Electric Co., Ltd.

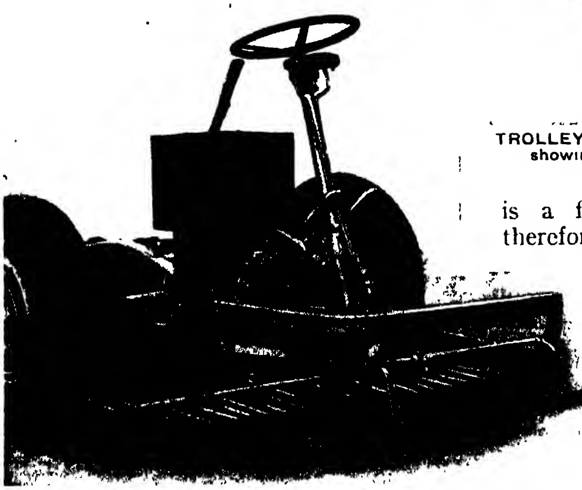


Fig. 3. Chassis at driver's end showing contro
Associated Equipment Co., Ltd.

and overhauls are unnecessary; the oi consumption of the power unit (*i.e.* th driving motor) is *nil;* daily inspection before a service period, is short an simple; no warming-up is necessary befor starting on service, and no precautions, a in I.C.E. vehicles, have to be taken i winter; fuel storage and special wate supply (for radiators) at garages ar unnecessary; and stops in service fo these items are also unnecessary.

The useful life of the power plant of trolley-bus is about 20 years, whereas tha of an internal-combustion engine for bu service is about 5 years. Moreover, o account of the absence of vibration, th chassis and body of the trolley-bus wil not depreciate so rapidly as those of th I.C.E. bus, and the full 20 years' lif will be possible for these parts.

Running Costs. The trolley-bus receive its energy from an electric supply system and the cost of this energy per kWI is a fixed quantity. It is possible, therefore, to compute fairly accurately the running costs of a trolley-bus, as variation of energy consumption due to abuse or inefficient operation is relatively small, whereas great variations on this account and on varying fuel costs must be allowed for in the I.C.E. bus.

Due to the long life of a trolley-bus the depreciation charges are lower than those for an I.C.E. bus. Customary values are: 10 per cent. for a trolley-bus, and 17 pe cent. for an I.C.E. bus.

As the capital costs of the new vehicles are approximately equal, the interest charges will be approximately the same for an equal number of vehicles in the two cases. But, due to the highe schedule speed of a trolley-bus, fewer o these vehicles may be required for a given service, thereby resulting in lowe interest charges.

In comparison with an I.C.E. bus, a trolley-bus suffers from the disadvantage that it is dependent upon an external electric supply system, and cannot operate unless overhead conductors connected therewith are erected along the whole length of each route.

The cost of this overhead equipment averages about £1,800 per mile for a double service, and the interest and depreciation charges thereon form a

standing charge which is peculiar to a trolley-bus system.

In view of the standing charge due to the electrical distribution system and overhead conductors, a trolley-bus system should operate in districts where a frequent service of vehicles is required, as in such cases the above standing charges may become a relatively small proportion of the total operating costs. In fact, the more frequent the service the lower will be the total operating cost per car mile.

Traffic with less than three services per hour (*i.e.* a headway exceeding 20 minutes) is unremunerative for trolley-bus operation. Such (country) services are best served by I.C.E. buses.

TROLLEY-BUS EQUIPMENT AND CONTROL

Power Unit. Present-day practice employs a single driving motor, which is rated at about 80 h.p. (1 hour), 500/550 volts; the continuous rating being about 60 h.p. The motor is capable of operating satisfactorily at currents 50 per cent. above the rated (1 hour) current, such currents being required during starting.

The motor is usually of the series-wound type, but in many cases a compound-wound motor is employed in order to obtain regenerative braking (with the corresponding saving in energy) and increased flexibility of speed control.

The motor is mounted in the forward portion of the chassis, in a position slightly to the rear of that which would be occupied by the engine of an I.C.E. bus. The same design of chassis is, in many cases, used for both vehicles. Fig. 2 is a typical example. The transmission is by a propeller shaft, with universal joints, to differential gearing in the back (driving) axle or axles, thus following the standard motor-vehicle practice.

Speed Control. When a single D.C. motor is started in the ordinary manner, by means of inserting and cutting out resistance in the armature circuit, the energy losses in the starting rheostat may be from 40 to 45 per cent. of the energy input from the supply system during the starting period. Expressed in another way, the energy losses during starting *are approximately equal to the energy output* from the motor during the starting period.

In the case of a trolley-bus working a service with 8 stops per mile at a schedule speed of 10 m.p.h., the number of starts per hour would be $8 \times 10 = 80$. Obviously in such a case the energy losses during starting form an important item in the annual energy account.

Low Rheostatic Losses. Low rheostatic losses during starting may be obtained by shortening the starting period and at the same time increasing the torque per ampère of current input to the motor. The latter requirement is necessary in order that the increased acceleration, corresponding to the shortened starting period, may be obtained without unduly increasing the current input to the motor.

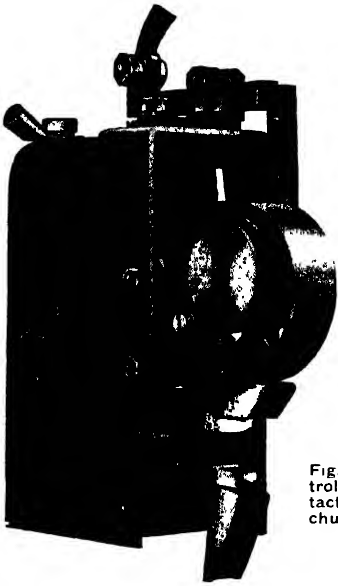
Since, in any D.C. motor, the torque per ampère is proportional to the flux, low rheostatic losses at starting can be obtained by increasing the flux during the starting period. Such a method is called "augmented field starting."

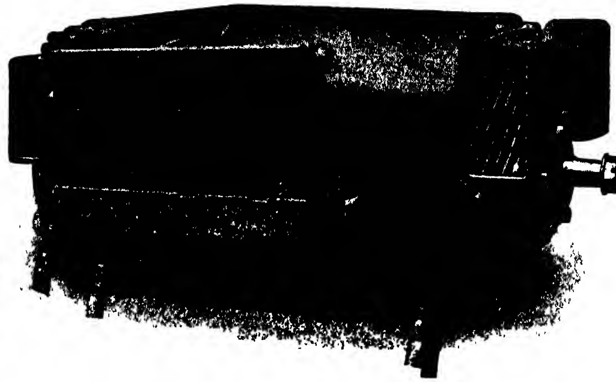
In the series-wound trolley-bus motor the number of turns provided on the field winding is larger than that necessary for normal running. At starting the full current passes through the field winding and a high flux is obtained, but immediately the starting rheostats are cut out current is diverted from the field winding so as to give the normal flux.

Field Control. For services with fewer stops per mile than the number (8) mentioned above a second diversion of current is usually provided in order to give the higher running speed which such service requires. The motor then operates under weakened field conditions.

With compound-wound (regenerative) motors the augmented field at starting, and the weakened field for the higher speed running, are obtained by controlling the current in the shunt winding by means of rheostats.

Braking. The braking system of a trolley-bus comprises: (1) power- or servo-operated mechanical brakes actuated by foot pedal, (2) hand-operated mechanical brakes actuated by hand lever, (3) electric (rheostatic or regenerative) brake. The mechanical brakes are compulsory, but the electric brake is optional; it is, however, usually fitted on account of the improved operating conditions thereby obtained.





TROLLEY-BUS. Fig. 4. 80-h.p. 500-volt, self-ventilated motor.

Fig. 5. Standard trolley-bus contactor with arc-chute removed.

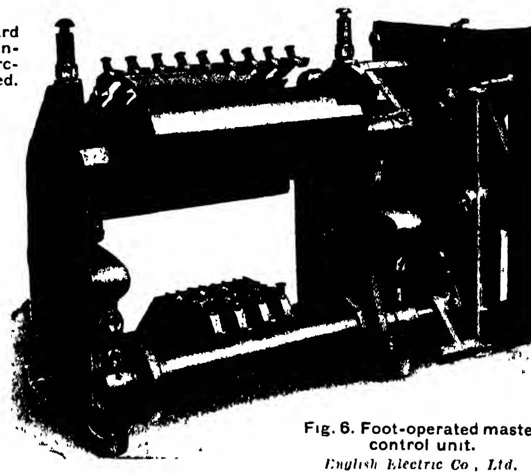


Fig. 6. Foot-operated master control unit.
English Electric Co., Ltd.

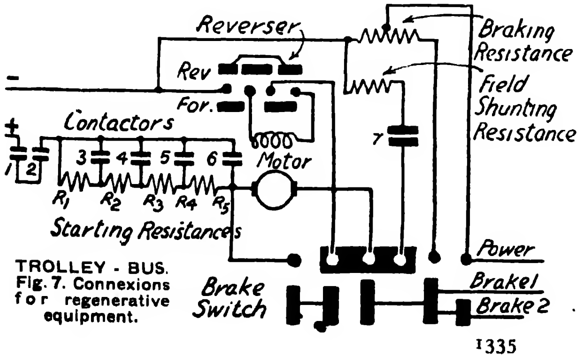
Rheostatic Braking. In rheostatic braking the motor operates as a self-excited generator and is loaded on rheostats. The braking torque is regulated by varying the resistance in the load circuit. Two steps only are usually provided.

When rheostatic braking is necessary with series-wound motors the *connexions between the armature and field windings must be reversed* in changing over from motoring to braking.

Regenerative Braking. This form of braking—in which the stored energy of the vehicle is converted into electrical energy and returned, less losses, to the supply system (*see* Regenerative Braking)—is, on trolley-buses, used only with compound-wound motor equipments. No reversal or change of connexions is necessary between motoring and braking.

Braking is obtained when the vehicle is running at speed—which would correspond to a weak shunt field excitation—by progressively increasing the shunt field excitation. This causes the motor to act as a generator (differentially compounded, in this case) and to feed back into the supply system. As the speed decreases, due to the braking action, so must the shunt excitation be increased, the braking ceasing when full shunt excitation is obtained.

Control Equipment. In all modern trolley-buses a remote-control system, working on similar lines to that on multiple-unit trains (*see* page 1301), is employed.



TROLLEY - BUS. Fig. 7. Connexions for regenerative equipment.

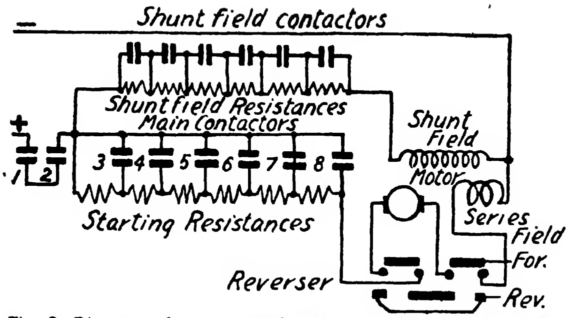


Fig. 8. Diagram of connexions for series motor equipment master controller.

The driver, therefore, has to operate only a small master controller. This operation is effected by the foot, and in many cases the pedal is of similar type to the accelerator pedal on a motor vehicle.

Main Controller. This is of the contactor type. The contactors are usually of the electro-magnetic type, but the electro-pneumatic type forms an alternative for those buses which have a compressed-air braking system.

With series-motor equipments seven or eight contactors are usually provided for starting, field shunting, and rheostatic braking. In such cases reversing is effected by a manually operated, drum-type, main-current, reversing switch incorporated in the master controller and suitably interlocked. A schematic diagram of connexions is shown in Fig. 7.

With compound-wound (regenerative) motor equipments, usually eight main contactors are provided for cutting out the starting resistances, and six auxiliary contactors for controlling the shunt field circuit. A schematic diagram of the connections is shown in Fig. 8.

The master controller may be arranged to give either step-by-step or automatic operation of the main controller. In the former case the master controller has a definite number of notches, to which it is moved by the pedal. At each notch contactors are energized to give the required circuit conditions.

With automatic control the first and second notches of the master controller give step-by-step control, as above, but on the succeeding notches the operation of the contactors is controlled by a current-limit, or accelerating relay, as in the automatic multiple-unit system. These contactors, therefore, can close, in order, only when the current input to the motor is below a predetermined value. If a full depression of the pedal is made after the second notch, the vehicle will be accelerated automatically to full speed, and the driver will be concerned only with the steering.

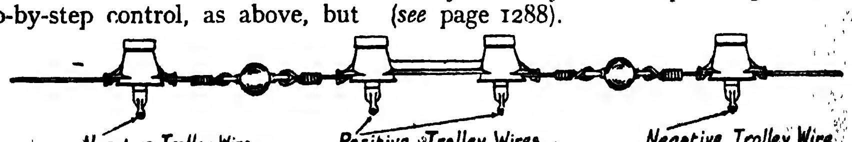
Combined Braking. When rheostatic braking is employed with series-motor equipments, the braking control is by the same pedal which operates the mechanical (*e.g.* compressed-air) brakes. The initial depression of the pedal operates the brake switch (which changes over the motor circuit to give the braking connexions) and gives the first step of the rheostatic brake. A further movement gives the second step of the rheostatic brake, and still further movement applies the air brake, in addition. The two steps of rheostatic braking are so arranged that a 12-ton bus can descend a gradient of 1 in 18 at speeds between 10 to 15 m.p.h. without the application of the mechanical brakes.

Current Collectors. The current is collected from the overhead conductors by a double swivelling trolley collector, which is mounted on a structural steel framework on the top of the bus. The trolley wheels are of the grooved, swivelling type, and are insulated from the trolley poles, which consist of tapered steel tubing. Pressure between trolley wheels and overhead conductors is effected by springs and levers at the base of each trolley pole.

When swivelling contacts are not fitted to the bases, the connecting cables extend direct to the car equipment. In this case a stop is fitted to the trolley base to prevent a complete rotation.

Overhead Equipment. The overhead equipment on a trolley-bus route must satisfy Ministry of Transport regulations (*see* page 1288).

Fig. 9. Overhead conductors for 2-way traffic.



Two conductors—one positive and one negative—are, of course, required for each direction of service, since there is no earth return as in tramways. With two-way traffic the conductors are arranged as shown in Fig. 9.

The method of suspension and the fittings employed follow standard tramway practice. In all cases double insulation (*i.e.* two insulators in series) is arranged for the positive conductor and single insulation for the negative.

TROUGH FITTINGS. This designation is applied to electric-light fittings having trough-shaped reflectors. There are three main types—showcase, cornice, and shop-window trough reflectors. Showcase troughs are usually of extremely simple design, the reflectors consisting of open troughs of parabolic cross-section, usually of nickel or chromium-plated sheet metal. They may be used with either tubular or general service lamps of 25–60 W. Cornice fittings are considered under the heading.

Shop-window troughs are larger than the other two and more rectangular in design (*see* Floodlighting). The reflecting surfaces consist of a number of ribbed mirrors specially disposed to give accurate light control, either of the intensive or extensive type, the former are used for lighting shop windows where the depth does not exceed two-thirds of the height.

The simplest method of wiring is to wire each length in parallel and connect to the supply by an ordinary lampholder or two-pin plug adaptor. *See* Lighting ; Lighting Fittings ; Shop-window Lighting.

TRUNK FEEDER. Term sometimes applied to feeders connecting or interconnecting generating and sub-stations. *See* Feeder.

TUBULAR HEATER. A low temperature heater in which an element operating well below red heat is mounted on a robust framework within a steel tube of heavy gauge. Tubular heaters are made in various lengths up to about 20 ft., and are suitable for heating rooms and buildings where the heat losses are low. They usually have a loading of from 40–60 watts per ft. run, and may, if so desired, be mounted in banks one above the other.

TUBULAR LAMP. Term applied to an electric incandescent lamp which has an approximately cylindrical bulb, the length of which is large in comparison with the diameter. Tubular lamps are always of the vacuum type. They may be either single or double ended. The filament is usually mounted on molybdenum supports inserted at intervals in a glass rod that runs the full length of tube. In the double-ended type the filament is connected at either end to a single contact cap, which in most makes is mounted on the end of the tube. Where it is desired to mount a number of these lamps close together, without a break in the line of light, lamps in which the caps are mounted on the side of the lamp (*see* Lamps, Electric) are recommended.

In the single-ended type the two ends of the filament are brought out to separate contacts on the same cap (as in the general service type), which may be either B.C. or E.S. Double-ended tubulars are used chiefly with trough fittings (*q.v.*).

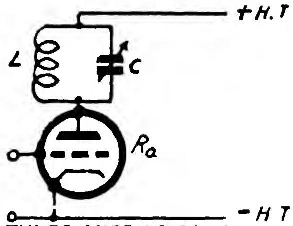
In a recent development, which merits notice, the filament is mounted on a flexible metal structure, which allows the tube to be bent or moulded to harmonize with and become an integral part of a decorative scheme. These lamps are manufactured in lengths up to 4 ft., and have diameters of the order of 30–40 mm. They consume from 30–40 watts per ft. run, and can for many purposes be used in preference to neon tubes, with which in regard to first cost they compare very favourably.

TUMBLER SWITCH. Term employed for the quick-break round knob switch commonly adopted for domestic lighting installations. Consists of a single-pole switch controlled by an insulated lever on the end of which is the knob. Pressing the lever operates the knife contacts through a link motion giving the necessary quick action. *See* Switch.

TUNED ANODE CIRCUIT. A circuit arrangement much used in connexion with valves operating at radio frequencies, particularly in the coupling of a high-frequency amplifying valve to a succeeding valve.

In the diagram the coil L and the condenser C comprise a tuned circuit connected in series with the anode of the valve. The impedance of the circuit is greatest at the resonant frequency, being L/CR ohms, where R is the effective high-frequency

resistance of the coil. This maximum impedance is called the "dynamic resistance" of the tuned circuit. If R_a is the anode A.C. resistance of the valve and μ the amplification factor, the voltage magnification obtained at the resonant frequency



TUNED ANODE CIRCUIT. The basic connexions.

(namely $\frac{1}{2\pi\sqrt{LC}}$ cycles per second),

is $\mu L/(L+CRR_a)$.

For applications of the circuit in amplifiers, *see* Anode Coupling; High-Frequency Amplification.

TUNGSTEN. One of the metallic elements. Its chemical symbol is W, and atomic weight 184. It is a hard, grey, brittle metal with the high melting point of 3,300° C.

Tungsten is largely used as an alloy to increase the hardness of steels, and drawn into a fine wire is used in the manufacture of incandescent lamp filaments to the exclusion of all other metals as described under the heading Metal Filament. It also forms the filament of the Tungar rectifier and the electrodes of the tungsten arc. In the Pointolite lamp tungsten is used, and it is also used as the filament in the Fleming oscillation valve. Thoriated tungsten filaments give off electrons to a much lower temperature than ordinary metal filaments, and this fact forms the basic principle of the dull emitter valve. *See also* Lamp; Valve, *etc.*

TUNNEL WINDING. An obsolete form of armature winding in which the conductors were entirely buried in the iron core, lying in holes within its mass. The iron channels were lined with tubes of micanite, press-spahn or similar insulation, and the insulated conductors drawn in. The centrifugal forces on the conductors were not as great as with smooth-core armatures (*q.v.*), but winding difficulties and lack of ventilation were disadvantages which could not be overcome. *See* Slotted Core Armature; Smooth Core Armature.

TURBO-ALTERNATOR. *See* Alternator.

TURBO-CONVERTER. *See* Converter.

TURBO-DYNAMO OR GENERATOR. *See* Generator.

TURNTABLE. *See* Gramophone (Electric) and Radio-Gramophone.

TWISTED SLEEVE JOINT. The method of jointing stranded cables by twisting the separate strands is described in detail under the heading Joints and Jointing (*q.v.*). For larger cables and particularly for aluminium conductors, a similar method of jointing is employed, in which a sleeve is drawn over the overlapping ends of the cables to be jointed and the whole twisted to form a strong mechanical joint. The sleeve is either tinned copper or aluminium according to the conductors concerned, and is sweated up solid after twisting, bringing the solder well over the joint between the sleeve and the cable at either side as well.

TWO-CORE CABLE. Also termed twin cable, contains two insulated cores not arranged concentrically. They may be laid alongside each other or twisted together according to the flexibility required. It is extensively employed for house wiring and also for D.C. power supply. *See* Cable.

TWO-PART TARIFF. With this the charge for an electricity supply is made up of two parts. One is always the kilowatt-hours consumed. The other may be the kilowatts of maximum demand. As this can only be measured by a rather expensive appliance some figure forming a rough guide to it is adopted for domestic consumers and other small supplies. This is, for instance, the number of points, number of lamps, floor space, rateable value of the premises.

The advantage of a two-part tariff is that it represents more accurately the actual cost to the supply undertaking than does a flat rate (*q.v.*). While the kilowatt-hour charge should cover chiefly the cost of coal, it must also contain certain other items which vary with the number of units supplied. These are, for instance, oil, water-stores, a proportion of repairs and maintenance costs and a small part of the wages bill. To these items the supply undertaking must add figures for certain costs occurring outside the generating stations, such as

something to cover ohmic losses in transmission and distribution, and a margin for profit. We thus arrive at a figure which will vary between about 1/5 of a penny to a large bulk consumer and about $\frac{3}{4}$d. for a householder. The kilowatt charge must cover the cost of interest on capital, a reasonable rate for depreciation, management, most of the cost of wages and salaries, a portion of the expenditure on repairs and maintenance and a small part of the coal bill to cover the cost of banking fires. A rough average charge per kilowatt maximum demand to a large consumer is £4 per year. *See* Tariff.

TWO-PHASE. Term used to denote a system in which there are two alternating voltages displaced in phase by 90° or one quarter of a period.

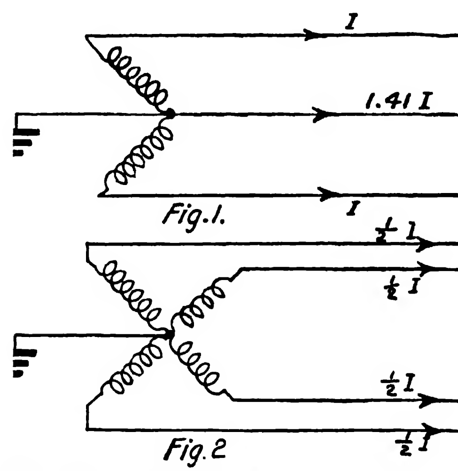
In place of a single coil rotating between the poles of the field magnets to generate a single-phase alternating voltage as described under Electro-Magnetic Machines (*q.v.*), two similar coils fixed at right angles to each other, rotating with constant velocity in a uniform field, will have E.M.F.'s induced in them, sinusoidal in character, and of the same maximum values and frequency. The maximum values in the two coils, however, will be attained at different times and, in fact, one sine wave will lag behind the other by a quarter of a period. This is the fundamental principle of two-phase generation. *See also* Single-Phase; Three-Phase.

Methods of distribution of two-phase supply will be found discussed under the succeeding articles on Two-Phase Four-Wire System; Two-Phase Three-Wire System, *etc.*

TWO-PHASE FOUR-WIRE SYSTEM. A system of alternating current supply in which the two phases are maintained entirely separate with two conductors per phase. The alternating difference of potential between one pair of conductors differs in phase by 90° from the difference of potential maintained between the other pair.

In England this system has only been used to a very limited extent, but, in some cases, stations which originally supplied only single-phase alternating current have been equipped with two-phase machines, and the two phases used separately to supply the old lighting circuits, but combined for power purposes. This method of effecting the change from single to polyphase supply has much to recommend it, for, if necessary, one set only of the coils of the two-phase machines may be used at first to supply single-phase current to the old network, and the other phase gradually loaded up until balance is obtained. Each motor is, of course, connected to both phases, in which case it will tend to balance the loads by drawing most power from the lightly loaded side. The economics resulting from the use of the two-phase four-wire system are further discussed under the heading Four-Wire System (*q.v.*).

TWO-PHASE THREE-WIRE SYSTEM. An alternating current system of supply in which three conductors are employed, one of which acts as a common return. An alternating difference of potential



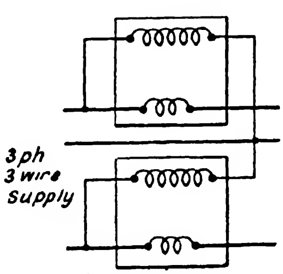
TWO-PHASE SYSTEMS. Figs. 1 and 2. Comparison of 3-wire and 4-wire distribution.

displaced in phase by one quarter of a period is maintained between this common return and each of the other two conductors.

This system is not so economical as the two-phase four-wire system with the centres of both phases earthed, for equal voltages to earth. For equal current densities it requires the same amount of copper as the corresponding three-phase three-wire system, whilst for equal efficiencies it requires 75 per cent. of the copper in the latter system. *See* Three-Wire System.

TWO-RATE METER. An integrating supply meter equipped with two separate registers and an electrically operated mechanism whereby the rotor of the meter can be geared to either of the registers at will by the control of the change-over mechanism. Two-rate meters are used in connexion with the two-rate tariff, in which the units consumed during the hours of peak demand are charged for at a higher rate than those used at other hours of the day. The change over of the meter mechanism, whereby the units used during the peak hours are recorded on the "high rate" register, and those used at other times on the "low rate" register, is made by means of a time switch controlling the supply to the solenoid which operates the change-over mechanism.

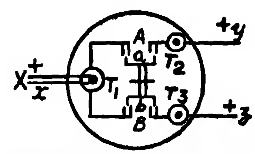
TWO-WATTMETER METHOD. The standard method of measuring power or energy in a three-phase three-wire circuit, by means of two wattmeter elements, which are either in separate cases, or are combined in one case to give an indication or registration corresponding to the total power or energy in them. The connexions of two wattmeters in a three-phase circuit are shown in the accompanying diagram. It is seen that this connexion is exactly the same as that of two meters used for measuring the energy in a direct-current three-wire circuit. The accuracy of the method for three-phase circuits can be understood, without mathematical demonstration, by recollecting that, at any instant, a three-phase circuit and a three-wire D.C. circuit are inherently identical in character. The total instantaneous torque on the wattmeters in the three-phase circuit thus corresponds to the total instantaneous power, and the sum of the deflections of the wattmeters gives the total average power in this circuit.



TWO-WATTMETER METHOD. The schematic lay-out.

TWO-WAY SWITCH. Various forms of tumbler switches have been devised to fulfil the requirements of different methods of control. Most of these are also used on one side of the supply circuit only, so that the danger of short-circuiting the main supply does not arise.

By far the most widely used of these special switches is the "two-way" switch, which allows a branch circuit to be controlled from two points which may be fairly distant from one another. The connexions of switches of this type are shown diagrammatically on the right. The incoming main X is attached to the terminal T_1, which is electrically connected to the near sides of the contact jaws of the breaks A and B, the far sides of the jaws being connected respectively to the terminals T_2 and T_3, to which the outgoing leads *y* and *z* are attached. There are two bridge pieces *a* and *b*, swivelling on a central axle and movable simultaneously by the same mechanism, in such a manner that when *a* closes the gap A, *b* is clear of the gap B and *vice versa*. Both bridges are shown above in the intermediate position with both gaps open, and some switches can be placed in this position. More usually, however, the switch can only be left hard over on one side or the other, and it is easier to secure the quick make-and-break when this is the case. *See* Intermediate Switch; Strapping Wires; Switch; Wiring, *etc.*



TWO-WAY SWITCH. The wiring connexions.

TWO-WIRE SYSTEM. A supply system employing two conductors between which the load is connected for direct current or for single-phase alternating current, one conductor being the lead and the other the return. In it all utilization devices are connected in parallel with one another. It is regularly employed in practice for supplying public lighting, for tramways and railways, and for small systems of supply and to private consumers.

For lighting incandescent lamps, steadiness of voltage is of the first importance. For arc lamps the same degree of steadiness is not demanded, while for power users (motors in factories, on tram-cars, etc.) the permissible variation is much greater. The generators are, in consequence, arranged to give a constant

voltage with varying current, or even to give slightly increasing voltage with increasing current, so that at higher currents the increased drop in the cables may be properly compensated for, and the consumer thus given a constant pressure.

It can hardly be too strongly emphasized that what is called a constant pressure is in reality only constant within definite limits, generally 6 per cent. of a declared value. The system demands a very heavy expenditure on copper as compared with a series distribution of the same power, but the circuits are safer than the series, owing to the employment, as a rule, of lower pressures.

The system is employed with both alternating and continuous currents, and the pressures are classed under either "low tension," or "high tension," or "extra-high tension." "Low" tensions range from 0 to 250 volts, "medium" from 250 to 650 volts, "high" from 650 to 3,000 volts, and "extra-high" from 3,000 volts upwards. *See* Direct Current; *also* Three-Wire System.

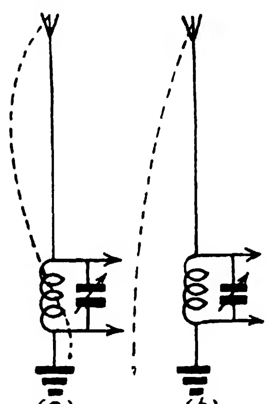
ULTRA-SHORT WAVES. Radio waves less than about 15 metres in length, differ in their behaviour from longer waves in that they are not reflected by the ionized layers of the upper atmosphere. Thus transmission from sending station to receiver can only be effected by the direct ray.

As it is found that these very short waves are rapidly attenuated by semi-conducting bodies in their path they do not follow the curvature of the earth's surface, and it is a general rule that reception can only be obtained at "optical" distances, that is, over a distance where the waves can travel in uninterrupted straight lines between transmitter and receiver. Consequently the range is limited to a few miles only at the earth's surface. A promising field of usefulness undoubtedly lies in ultra-short wave communication between an aeroplane and the ground, where "optical" distances increase with the altitude of the machine.

The technique of television transmission calls for ultra-short waves, and so practical development in this direction is a matter of importance for the continued progress of television.

The generation of the very high frequencies representing ultra-short waves presents no insuperable difficulties, and the transmitting aerial system can be designed to give directional transmission with comparative ease.

The conditions at the receiver are generally more difficult than at longer wavelengths, not only on account of the high frequencies involved but also due to the fact that nodes and antinodes of current are liable to occur in the receiving aerial system. As the tuning capacity is varied the position of a node changes its position along the aerial, and when it occurs at the point where the inductance coil is connected, no reception is possible, the particular position on the tuning condenser being known as a "blind spot." This condition is illustrated in diagram (*a*), where horizontal distances between the curve and the vertical line of the aerial represent the aerial current at various points.



ULTRA-SHORT WAVES. Current distribution in the aerial.

On the other hand, an antinode may occur at the coupling coil as at (*b*) giving maximum sensitivity, the tuning point on the condenser being a "sensitive spot." The blind spot can be shifted by connecting a coil or condenser in series with the aerial.

The methods of reception used for ordinary short wavelengths can be applied successfully to wavelengths down to about 7 metres, the well-tried reacting detector circuit being particularly satisfactory. But for lower wavelengths very special precautions have to be taken to reduce the effects of stray capacity. All components must be as small as possible, and all connexions (except valve grid and anode) to the actual oscillatory circuit should be made at points of zero H.F. potential.

ULTRA-VIOLET LIGHT APPARATUS

By E. H. W. Banner, M.Sc., A.M.I.E.E., F.Inst.P.

Here one of the most modern applications of electricity is outlined from all its aspects, medical, industrial and general. The theory is authoritatively explained, the apparatus is described and a special section is devoted to problems of installation and maintenance. See Angstrom Units; Light; X-Rays.

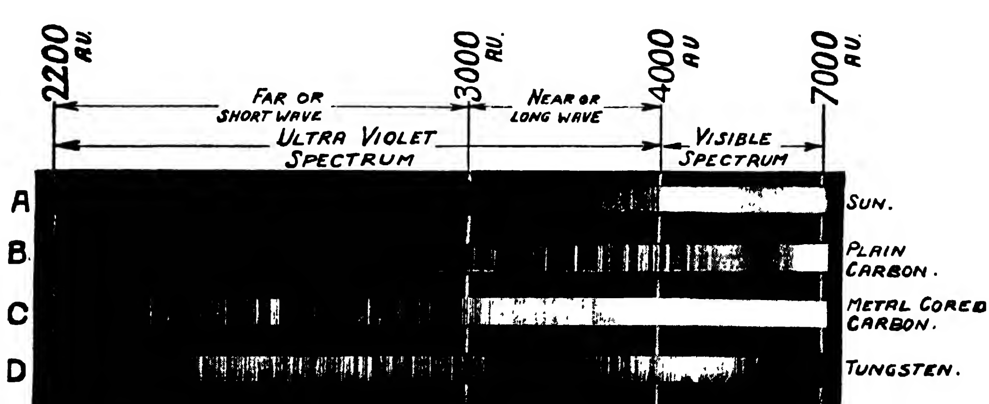
The term " light " usually means visible light; rays that are outside the range of vision are, of course, invisible, but generally there are visible rays also, so that whilst ultra-violet rays themselves are not seen they are usually associated with visible light. Thus, any lamp generating ultra-violet light also generates visible light, and for occasions when visible light also is not required these visible rays have to be filtered out.

The term " ultra-violet rays " is commonly used and is correct if not to be confused with " violet rays." These latter " rays " are entirely different and are really an accidentally produced fluorescence due to high-frequency currents. The merit of this latter application is entirely in the high-frequency current and the violet glow is of no consequence other than showing that the apparatus is working correctly.

Position in the Spectrum. Visible light extends from the violet to the red, covering wavelengths of from 3,969 Å to 6,563 Å (Å or A.U. is the Angstrom unit (*q.v.*) and equals 10^{-10} metre so that light wavelengths are of the order of a third to two-thirds of a millionth of a metre). Ultra-violet rays therefore are of lower wavelength than 4,000 Å and extend to about 1,800 Å. This band is divided into two parts and comprises the " near " or long-wave rays and the " far " or short-wave rays. The " near " rays are those near the visible rays whilst the " far " rays border on X-rays.

Different types of lamp produce different kinds of radiation; no one lamp will produce either type of rays at will. The ultra-violet accompanying sunlight is chiefly the near rays as the long waves are absorbed by the air, particularly impure air which is normal except on high snow-covered mountains.

The wavelength and the frequency of all radiations are related in a well-known way; for electro-magnetic radiations, covering wireless, heat, light, X-rays, etc., the relation is frequency × wavelength = velocity of light. Thus the longer the wavelength the lower the frequency. For electric supplies at 50 cycles per second, the standard frequency in this



ULTRA-VIOLET LIGHT APPARATUS. Fig. 1. The relative spectra of various forms of illuminants, showing the proportions of radiated energy emitted in the ultra-violet section. The sun is seen to be comparatively deficient in ultra-violet radiation.

Courtesy Schall & Son, Ltd

country, the wavelength is 6 million metres, whilst the ultra-violet range is of the order of 10^{15} cycles per second.

Physical, Chemical and Biological Effects. When ultra-violet light falls on a substance various effects may take place. The molecules of which the substance is composed may be disintegrated and a new physical condition result. Photo-electricity, fluorescence and phosphorescence are examples of physical changes that may occur due to ultra-violet light. Chemical changes take place in some substances so that the general appearance and constitution may be altered and apparent either to the eye or by a chemical analysis. The rays also affect a photographic plate—another chemical effect. The third type of change is the biological, or the effect on the human body. Sunburn is a common example of biological change due to ultra-violet light, usually from prolonged exposure to sunlight. Exactly similar results are obtained by ultra-violet light artificially generated, but much more pronounced, due to the higher efficiency of generation, which is local and not passed through a considerable thickness of the atmosphere.

ULTRA-VIOLET LIGHT APPARATUS. Fig. 2. Small radiator for home use. British Hanovia Quartz Lamp Co., Ltd.

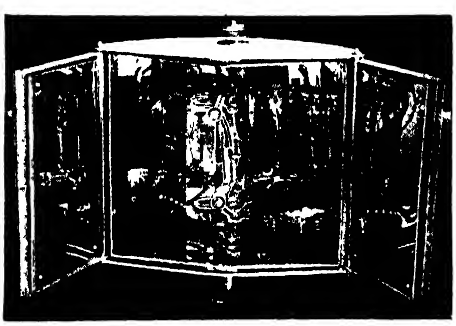


Fig. 3. Reflector and burner of "Alpine Sun" lamp. British Hanovia Quartz Lamp Co., Ltd.

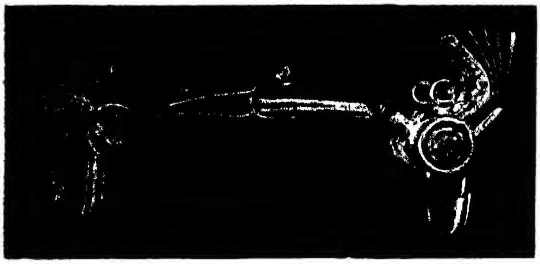
Near and far ultra-violet light have different effects on the body and in general are used for different purposes. Like most things, ultra-violet rays are beneficial if correctly applied and controlled and harmful if carelessly used. Correct doses of ultra-violet light of appropriate wavelength may be administered to anyone as a general tonic, in the same way as sunshine is beneficial if used intelligently. On the other hand, other rays are harmful if not administered by an experienced worker who is necessarily a doctor experienced with ultra-violet light. Either experience without the other is dangerous.

For a general tonic the near or long-wave radiation is used (this is nearest to sunlight), and for local treatment (or therapy, as it is termed) the far or short waves are required. The long waves are absorbed by the cells of the body so that in general only outward effects are produced by such radiation. For specific troubles such as treatment of wounds and tubercular conditions doses of short-wave ultra-violet light are beneficial, but care is needed in their administration.

ULTRA-VIOLET APPARATUS

U.-V. Lamps. Two general types of lamp are in common use; arcs in air and arcs in mercury vapour. As has been stated, no one type of lamp will produce every wavelength required, so that for various purposes different lamps are used. A further consideration, apart from the economic one, is that of supply—D.C. or A.C.

Arcs in air are usually between carbon electrodes. (*See* Arc Lamp.) The amount of ultra-violet which is generated in addition to the visible light depends on the amount of various salts impregnated in the carbons. Plain carbons produce light very similar to daylight, whilst the inclusion of a core of nickel generates a greater proportion of long-wave ultra-violet light. Tungsten-cored carbons generate shorter waves and so are of use for surgical or local therapy.



ULTRA-VIOLET LIGHT APPARATUS. Fig. 4 (a). The lamp burner from Fig. 3.
British Hanovia Quartz Lamp Co., Ltd

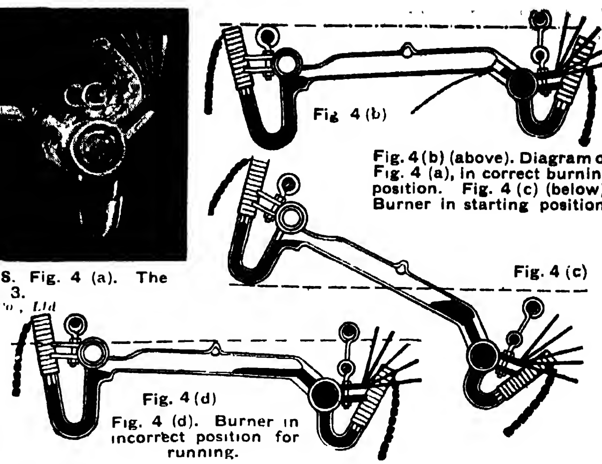


Fig. 4 (b) (above). Diagram of Fig. 4 (a), in correct burning position. Fig. 4 (c) (below). Burner in starting position.

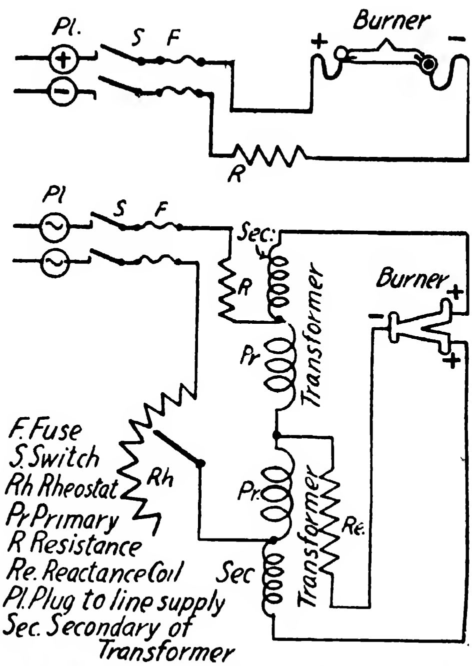
Fig. 4 (d). Burner in incorrect position for running.

With all carbon arcs a considerable amount of heat is generated also. Such arcs require about 5 to 20 ampères with a volt drop of about 60 volts, and it is possible for two or more to be run in series so as to reduce the loss in series resistance. Some resistance is necessary, however, to maintain the arcs stable. Starting an arc with no resistance in series would quickly blow the fuses as the result is practically a short circuit. Arc lamps may be hand-fed or automatic as explained under the heading Arc Lamp.

Another type of lamp is the tungsten arc. In this lamp pure tungsten electrodes are used and the arc will only operate on D.C., unlike the carbon arc, which will work equally on D.C. or A.C. Tungsten arcs produce more far or short-wave radiation than do carbon arcs and so are of more use for local or surgical therapy. Other metal electrodes generate ultra-violet light also and will only run on D.C.

Quartz Mercury Vapour Lamp. The third and probably the most important type of lamp is the quartz mercury vapour lamp. This consists of a quartz tube (which is usually evacuated of air) and the arc is drawn out in mercury vapour, giving it a greenish colour, and having very little heat rays. This type of radiation is sometimes termed "cold light" for this reason. The light contains some long-wave rays, but is extremely rich in short waves, and so is in considerable use for local therapy for particular ailments. The quartz tube is necessary, as it is one of the few materials that is transparent to ultra-violet light of short wavelengths.

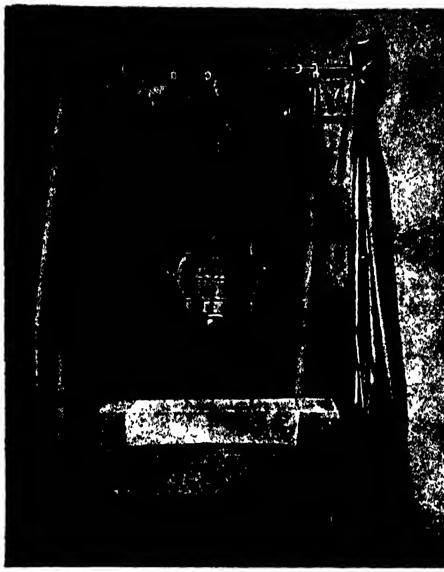
Usually the quartz tube is sealed and evacuated, but some lamps have the tube open to the air. Mercury vapour is still the conducting medium between the electrodes, however. The lamp is slightly different for A.C. or D.C. Some heat is necessarily generated, and at the ends of the tube are fins for radiating heat. The quartz burner is fragile and great care has to be taken in transit as the mercury is heavy and is liable to break the tube on being rapidly tilted. The atmospheric



Figs. 4 (e & f). Wiring connexions for the burners on D.C. and A.C. supply systems.

type has the advantage that, as it is not sealed, the mercury may be removed for transport. On the other hand the mercury oxidizes in the air and in general the evacuated and sealed type is better. With both types the quartz is subject to discoloration with time, leading to a loss in the amount of transmitted ultra-violet light.

A further type of ultra-violet lamp, not much used in this country, is the cadmium quartz lamp. This is somewhat similar to the mercury vapour lamp, but contains a small quantity of cadmium which is solid when cold and vaporizes after switching on; no tilting is necessary to start. It is only supplied for operation on 220 volts A.C. and can replace a mercury vapour lamp for many purposes. The light is rich in long-wave ultra-violet light.



ULTRA-VIOLET LIGHT APPARATUS. Fig. 5. Mercury vapour analytical lamp, for scientific and commercial use.
British Hanovia Quartz Lamp Co., Ltd.

Incandescent Lamps. Some incandescent lamps are advertised as being ultra-violet lamps. This is true only to a limited extent as the glass bulb, although of special glass, is by no means as transparent to ultra-violet light as is quartz. The ultra-violet light is obtained by overrunning the filament so that the life is very short. They are of some use for general or constitutional therapy and may be run for long periods near the body without special precautions.

COSTS AND APPLICATIONS

Apart from the question of the most suitable radiation, the questions of costs arise. Costs are of two kinds, initial and running costs.

Included in initial costs is the question of life as replacements have to be provided.

Costs: Carbon Arcs. Initial cost £10 to £40, depending on hand or automatic feed, and on size (5 to 20 ampères). Running costs: carbons about 3d. per hour; current with 20 ampères and 60 volts about 3d. per hour, total costs say 6d. per hour. If the supply is A.C. a transformer is required, whilst if D.C. and only one arc, a series resistance will absorb most of the voltage; on 230-volt mains it will waste 170 volts and so increase the total running cost to about 1s. 3d. per hour.

The use of three arcs in series therefore does not increase the cost for current, but it does increase the carbon replacement cost. For a single lamp on D.C. a motor generator is an alternative, but not common on account of its high first cost, although it does reduce the running costs. The cost of carbons varies with the impregnation and, although an approximate average is given, the different costs for plain iron, or nickel core and tungsten core vary approximately as $1/1\frac{1}{2}/4$. A maximum output of ultra-violet occurs when the positive carbon is at the bottom and with a long arc so that the volt drop is high and the watts are a maximum.

Costs: Tungsten Arcs. The usual current is 5 ampères and the volt drop 60 volts, but being D.C. there is a high resistance loss; this is approximately 1d. to 2d. per hour. Tungsten electrodes are expensive and burn about $\frac{3}{4}$ inch each per hour. The electrodes cost about 2s. 6d. per inch so that the replacement cost is about 3s. 9d. per hour and the total running cost about 3s. 10d. per hour. As the current cost is small compared with the replacement cost the use of a motor generator for reducing to 60 volts D.C. is not economical, series resistance being usual unless several are operated in series.

Costs: Mercury Vapour Lamps. Initial costs are fairly high—£20 to £50; the replacement cost must be considered as

the life is about 1,000 hours, due to discoloration, and after this period the amount of ultra-violet light transmitted is considerably less than when new; this is about £9. Thus it may be considered to be 2d. to 3d. per hour. Current costs are based on consumptions of from 220 to 1,000 watts and may be called 1d. to 3d. per hour. Thus the total running costs become about 4d. to 6d. per hour. This type of lamp is therefore the cheapest in running costs and is in most general use for professional purposes, *i.e.* surgical, chemical, and other industrial work, as apart from occasional use or for general therapy where a carbon arc generating "near" ultra-violet is sufficient.

ULTRA-VIOLET LIGHT APPARATUS
Fig. 6. A tonsil irradiator in operation.
British Hanovia Quart. Lamp Co., Ltd.

Applications. Whilst the use of ultra-violet light in therapy, both general and local, has been mentioned, other uses are of equal importance, chiefly in industry. Analysis of various foodstuffs and materials is a definite field, as is also the examination of pictures, bank notes, etc., for forgery. If a picture is overpainted with a second picture ordinary light will not show the under picture, but the application of ultra-violet light will do so (as also will X-rays), particularly if the first painting is very old and painted with pigments now not in use. Documents suspected of forgery are also examined in the same manner.

Minerals fluoresce with colours entirely unsuspected and a valuable method of identity and analysis results. Analytic lamps often have a light filter by which no visible rays are passed so that viewing such minerals by the true ultra-violet light they become visible but entirely different from the daylight appearance.

If the light is to be viewed, goggles must be worn as such light is harmful to the eye.

This is always necessary for therapy, where the patient and operator need to wear the correct goggles as supplied by the lamp maker.

Some of the industries in which ultra-violet light analysis is regularly used are as follows: Foodstuffs: sugar and jam; brewing; eggs; wines; flour and seeds; oils and fats; cheese, etc. Police work: detection of blood, etc.; examination of papers for secret writing. Drugs and chemicals. Medical, other than therapy treatment: diagnosis of various skin diseases; examination of food for contamination from metal vessels, etc. Philately. Metallurgical: slags, ceramics and glassware properties. Tanning and paper manufacture. Textiles. Colours and varnishes. Rubber: analysis and ageing by exposure. Fuel oils.

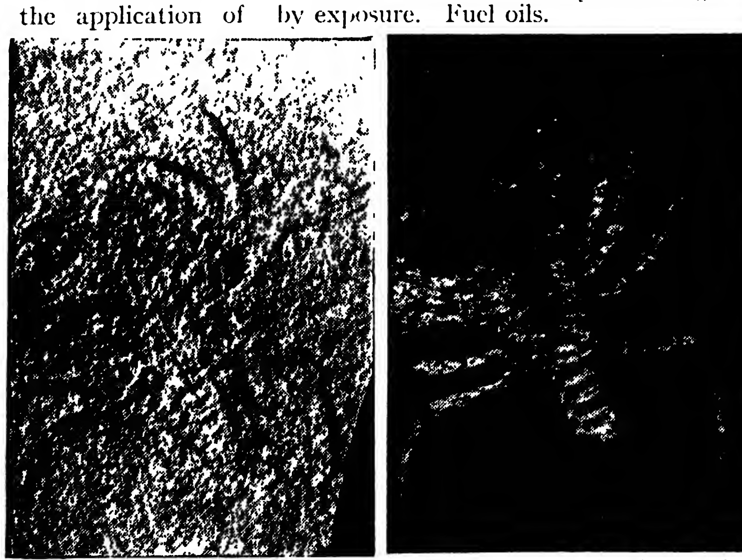


Fig. 7 (a and b). Photograph of fossil (a) in daylight; (b) in ultra-violet radiation.
British Hanovia Quartz Lamp Co., Ltd.

INSTALLATION AND MAINTENANCE

The provision of wiring and control gear for ultra-violet lamps is a non-specialized job that may be required of any electrician. The chief points to be considered are (1) whether the lamp requires D.C. or A.C.; (2) whether more than one arc in series on D.C. or with a transformer for A.C.; (3) total consumption in ampères required from the mains; (4) whether the supply mains available at the point required are sufficient for the load.

If the lamp, of whatever type, is supplied for D.C. only, then it must be used on D.C. If D.C. mains are not available either a motor generator, rotary converter or static rectifier must be employed. If one of these is used the approximate running periods of the lamp should be ascertained, as if only very short periods are required it will be possible to install a smaller machine or rectifier than is necessary for continuous operation.

A.C. mains are now common so that it is likely that an A.C. lamp with a transformer will be used. In this way the current from the mains will be appreciably less than the lamp current, and will often be not more than 1 kilowatt. Wiring for such loads is quite straightforward and no more expensive than "power" wiring in a house. A double-pole switch and fuses, preferably of the self-contained metal-clad pattern, are advisable, and the flexible lead should be kept as short as possible. The question of earthing the metal stand of the lamp is not generally agreed upon and the same considerations apply as to earthing any other apparatus in a house or consulting-room.

Usually no ammeter is included in the circuit, but with some lamps this is advisable. Special lamps having a higher intrinsic brilliancy, *i.e.* a higher candle-power per unit area of the source, are used for some analytical and industrial purposes, and these are rather more tricky to operate than the ordinary mercury vapour lamp. In one lamp the starting current is about 4 ampères, but when hot and working normally, the current must not exceed 3·5 ampères. The use of an ammeter and rheostat is therefore necessary in such cases. The ammeter should be of first grade accuracy, but may be quite small—and a 2½-inch instrument is suitable. If for A.C., it will be of the moving-iron type, and if D.C., moving-coil.

Lamps requiring several kilowatts are unusual, but may be encountered in large hospitals and clinics. Alternatively, a number of small or medium-sized lamps may be run in adjacent rooms from one set of mains and main switch. Should the total load be about 5–10 kilowatts it is necessary to ensure that the cables are sufficient for the load, and that they connect to suitable mains. For example, it is useless running cables for, say, 30 ampères to a distribution board only designed for 15 ampères per way. Cables must extend back to suitable mains.

There is another reason for this, and that is that switching on and off a heavy load causes a voltage change in other apparatus on the same mains so that an objectionable flicker is caused. If X-ray apparatus is operated on the same mains the fluctuation caused by switching on or off lamps may seriously interfere with good results from the X-ray set, due to uncontrolled voltage changes.

Power factor may be ignored on A.C. lamps as the load is resistance-controlled and so nearly unity. If reactances were used for voltage reduction, then there would be a discrepancy between the size of cables necessary for the current and the watt rating of the lamps.

Some lamps intended for local therapy are water-cooled so that the lamp may be placed very close to the patient. Some of these lamps have their own circulatory system; others need connexion to a water supply. It is essential to ensure that the water supply is adequate and as instructed by the makers, and that it is turned on first and off last.

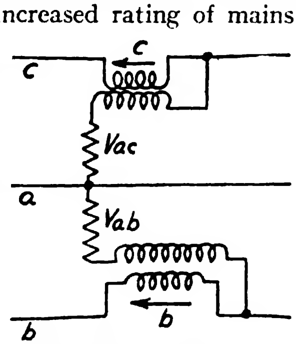
Faults and Maintenance. Little can be stated under this heading as many of the lamps are proprietary and should be returned to the maker on a defect occurring so as to keep within the guarantee of performance. Faults that may arise, other than breakage, include mechanism faults on arc lamps of the automatic feed pattern. The coils may have developed shorts or open circuits and should be tested and rewound, if necessary. Carbons need replacing and the correct size and grade of carbon should be used.

If any suspicion arises that a mercury vapour lamp is less bright or the results are less noticeable, the working period should be estimated. If the period is of the order of 1,000 working hours, then as much life has been obtained as can be expected, and a new burner is required. The possibility of poor output due to low voltage or damage due to high voltage should not be forgotten, and a test made with a voltmeter or ammeter.

Interference. Interference to radio sets caused by ultra-violet lamps is slight, as a rule, unlike some other electro-medical apparatus such as high-frequency (violet-ray), hair dryers, small vibrating and rotating machinery and parts. If a rectifier is used to convert A.C. to operate a D.C. lamp more trouble may be expected than if a lamp is run directly on the mains.

Interference can be overcome by screening, particularly if the apparatus is in a metal case which may be earthed. Where screening is not practicable the simplest way is to connect a 2 μF condenser from each line to earth, preferably through fuses. In rare cases chokes in series with each lead may be necessary.

UNBALANCED LOAD. When the loads connected to the two sides of a three-wire system or in the three branches of a three-phase circuit are unequal, several undesirable effects result. In the first place, an increased rating of mains and transforming plant is required, the negative sequence currents flowing in the return representing energy loss analogous to the wattless components of current in a balanced circuit. Secondly, the rotating machines in the circuit sacrifice efficiency in their inherent tendency to restore phase balance. Thirdly, complications arise in the measurement of the power quantities in the circuit, separate wattmeters being connected in each phase, or two wattmeters are employed, combined in a single instrument and connected to the phases in such a way as to give the total power in a single reading, as shown in the diagram. Accordingly all supply companies take steps to see that the loads on their mains are balanced, requiring large consumers to arrange for correct balancing on all new or altered installations. *See* Balanced Load.



UNBALANCED LOAD. *a, b, c* are three phases; *c, b* current coils; *Vac., Vab.,* voltage coils.

UNDERGROUND CABLE. *See* Cable.

UNDER-VOLTAGE CIRCUIT BREAKER, RELAY, etc. *See* Minimum Circuit Breaker, *etc.*

UNIT OF ELECTRICITY (SUPPLY). Otherwise known as the Board of Trade Unit (*q.v.*), the unit is equivalent to 1,000 watts per hour or 1 kilowatt hour.

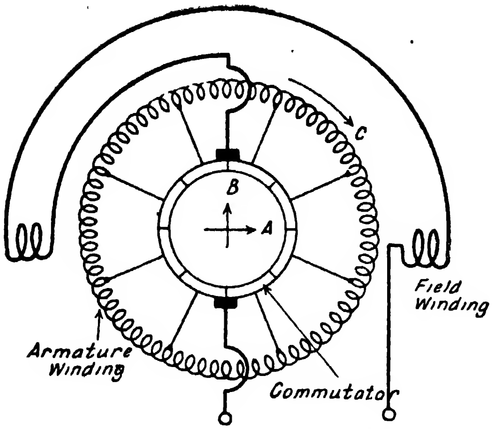
UNIT(S). The development of the science of electricity involved the adoption of some means of numerical specification of the quantities, and various systems of units were therefore introduced.

The first step was towards the expression of the electric and magnetic quantities in terms of length, mass and time; that is in terms of centimetres, grammes and seconds, the so-called C.G.S. system which had served so well for ordinary mechanics.

These units were unsuited for practical use, however, and the more workable International Units were therefore introduced, employing standards of comparison in actual physical constants for the volt, ampère and ohm. Secondary and tertiary units such as the coulomb, the watt, the gauss, the maxwell, the henry, etc., were then developed from these standards, and will be found discussed in this work under their respective headings.

Other units employed in this encyclopedia, though not necessarily of electrical derivation, will be found discussed under the following headings: Absolute; Ångström; Board of Trade; British Thermal; C.G.S.; Decibel; Electro-Magnetic; Fundamental; International; Practical, *etc.*

UNIVERSAL MOTOR. An electric motor which will operate satisfactorily with D.C. or A.C. of any commercial frequency and with voltages varying over a wide range. The motor is also known as the single-phase series motor. When operated with A.C. it runs at a speed which is independent of the frequency of the supply.



UNIVERSAL MOTOR. Fig. 1. A, direction of field magnetism ; B, direction of armature magnetism ; C, direction of rotation.

This type of motor has the obvious advantage that it can be connected to any type of supply, and is therefore widely used for such domestic purposes as vacuum cleaning.

When operated with D.C. the motor behaves exactly like a D.C. series motor. The current circulates through a field winding and an armature winding which are connected in series with each other.

The armature is similar to that of a D.C. machine. The magnetic effects of the field current and the armature current are at right angles to each other, and the armature therefore exerts an effort to set its magnetism in line with that of the field. As in the case of the D.C. series motor, the direction of the driving force is independent of the direction of the current. This is illustrated in Fig. 1, which shows a schematic diagram of the main field and armature. If the current is reversed both the arrows representing magnetism are reversed so the armature still exerts a turning force in the same direction.

If the direction of the current is changed at regular intervals the motor will go on running in the same direction. It will therefore rotate with alternating current.

An ordinary D.C. series motor would not give satisfactory operation with A.C. because the solid iron poles would have eddy currents induced in them by the pulsating field; also the power factor would be extremely low, due to the inductance of the field and armature windings. To overcome these difficulties the field magnets are built up with laminated plates like the core of a transformer, so as to reduce the eddy currents.

Design. The air-gap between the armature and the pole faces is reduced to the smallest amount mechanically possible and the cross-section of the field magnets are increased so as to reduce the number of field ampère-turns necessary to produce the required field strength. This reduces the inductance of the field winding. To reduce the inductance of the armature winding a stationary compensating winding is provided, the ampère-turns of which oppose those of the armature. The compensating winding is as nearly as possible a counterpart of the armature winding. In small domestic motors the compensating winding is not usually fitted. When used with alternating current the difficulties of commutation are increased by the current induced in the coil undergoing commutation by the pulsating field. To overcome this difficulty some motors have high-resistance connexions between the armature and the commutator. This reduces sparking, but leads to loss of power and consequent over-heating.

Fig. 2 illustrates diagrammatically the above refinements in design.

Universal motors are obtainable in all sizes from very small fractions of one horse-power (*see* Fractional Horse-Power Motor) to heavy power drives such as for railway locomotives. For heavy powers they are usually operated at a frequency

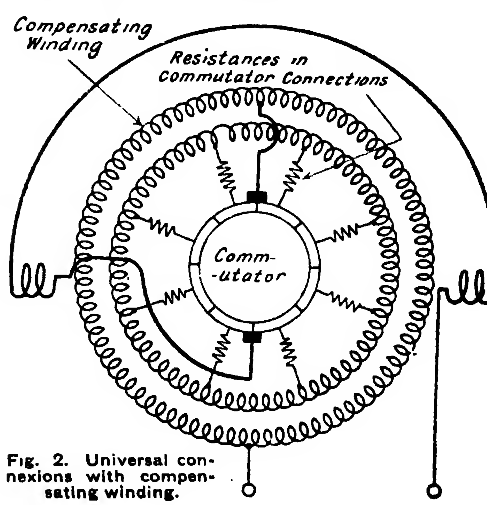


Fig. 2. Universal connexions with compensating winding.

of 16 or 25 cycles (*see* Single-Phase Motor). Their chief use, however, is in domestic and all small portable apparatus. The modern tendency appears to be to discontinue their use for heavy drives.

When ordering a universal motor or a piece of apparatus containing a universal motor it is advisable to state the type D.C. or A.C. and frequency and voltage of the supply, although the same motor will operate well at any type or frequency of supply up to, say 100. The voltage at which the motor is operated should not be more than 10 per cent. above or below the designed voltage. For instance, a 200-volt motor should operate between 180 and 220 volts. *See* Fractional H.P. Motor.

UNIVERSAL SHUNT. *See* Shunt Box.

"V" Abbreviation for volt (*q v.*) and the usual symbol for potential. A distinction must be made between *e*, the symbol for E.M.F., and the symbol V. Thus the E.M.F. of a generator is given by $e = 11{,}000$ V. (say) obtained by calculation of the rate of cutting of armature flux. *See* Electro-Motive Force.

"v." Symbol for velocity of propagation of electro-magnetic waves in free space. Usually reckoned for light waves as equal to 186,000 miles per second or 3×10^{10} cm. per sec., but more accurately $2{\cdot}9982 \times 10^{10}$ cm. per sec. *See* Electro-Magnetic Theory of Light.

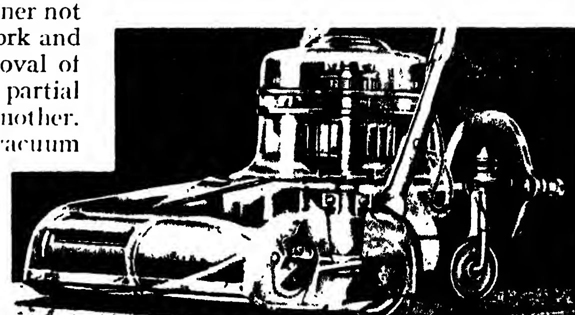
V.A. Abbreviation for Volt-Ampère.

VACUUM CLEANER. In no sphere, other than that of lighting, has electricity proved so popular in domestic service as in cleaning. The electric vacuum cleaner not only saves the user a lot of hard work and much time, but it effects the removal of dust and dirt rather than its partial displacement from one place to another.

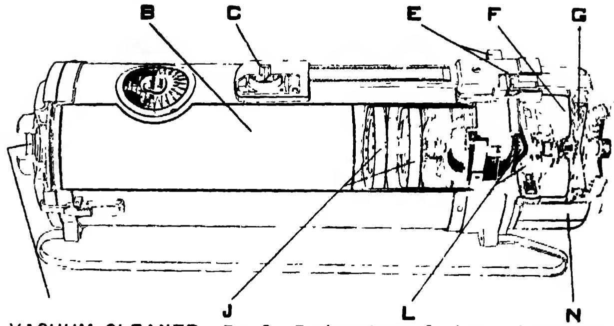
The principle on which all vacuum cleaners function is the removal of dirt by suction. A small electric motor drives an impeller type fan which creates a partial vacuum in the suction pipe. Air is thus drawn in at the nozzle, carrying with it dirt and dust suspended in the air current. This is discharged into a filter bag, sufficiently porous to allow the air to escape, but in which the dust is trapped. Periodically the dust bag has to be removed and emptied, to prevent it becoming choked up. The basic operating principle does not vary, either for portable machines or stationary plants. Domestic machines divide broadly into two classes, the "bag and stick" and "cylinder" models. The respective characteristics of these two types are discussed below.

"Bag and Stick" Type. A machine of this class is shown in Fig. 1. It may be described as a suction broom, since it is pushed about over the carpet in much the same manner as a broom, the essential difference being that the dust is sucked up through the nozzle and deposited in the dust bag carried at the side of the "stick" handle. The head of the machine carries the motor and the fan which is contained in the suction chamber, which is extended to form the nozzle. The machine is mounted on wheels, for easy manœuvring; means are provided to adjust the height of the nozzle to conform to different thickness of pile; and the handle can be brought low down to the horizontal to enable the machine to be pushed under furniture. Supply to the motor is given through flexible cable. Switch control is provided on the machine.

Suction alone will effect the major work of cleaning, but embedded fluff, cotton threads, etc., in the carpet pile are difficult to remove unless means to disturb them are provided. This is variously done by fitting a motor-driven brush in the nozzle; a brush operated by the running wheels as the machine is pushed over the carpet; a motor-driven "beater"; or a



VACUUM CLEANER. Transparency view of a bag and stick type cleaner.
Courtesy Hoover Ltd.



VACUUM CLEANER. Fig 2 B, dust bag ; C, dust indicator ; E, insulating switchbar , F, protection hood over motor ; G, double air-purifying pad ; H, insulating socket J, compound fan undercut commutator and carbon brushes , N, filter housing insulating material.

Courtesy of Electrolux, Ltd

fixed brush or toothed bar in the nozzle. Naturally the motor-driven brush or beater effects the required purpose most definitely, but the wear on the pile of cheaper carpets is likely to be greater than with non-motor-driven devices. A point to watch with motor-driven brush machines is not to leave the machine running if called away when using the cleaner, as there is the risk that on returning it may be found that the carpet under the nozzle has been badly worn.

Cylinder-Type Machines. An example of this class of cleaner is shown in Fig. 2. The operating principle is precisely as described above, but the motor, fan and dust bag are accommodated within a cylindrical case, and the suction nozzle is connected thereto by a flexible hose. The cylinder is either mounted on wheels or skids. With the cylinder-type machine there is far less weight actually moved about when manipulating the nozzle, and it is more easy to get the nozzle (which is carried on a swivel joint) under low furniture and into awkward corners. On the other hand, a motor-driven brush or beater is out of the question with this type of machine, and it is, perhaps, in consequence a little less effective as a carpet cleaner.

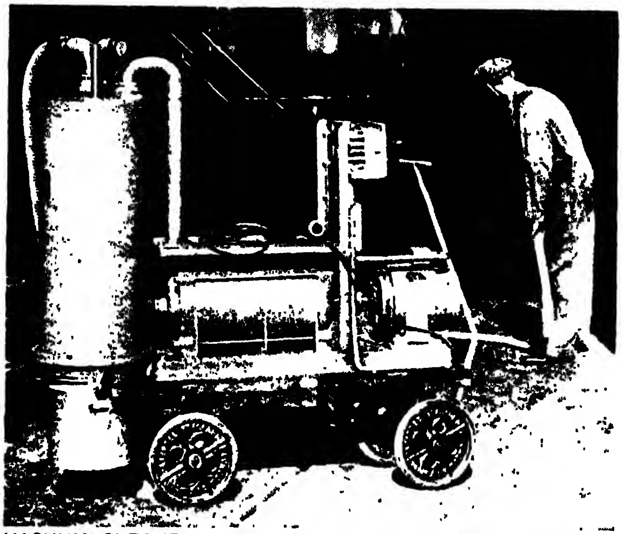
A variation of the cyclinder machine is the design in which the motor, fan and dust bag are accommodated in a container provided with lifting handle, so that it can be conveniently carried from place to place as circumstances require. Various accessories in the form of hose, brush and mop attachments are usually supplied to meet domestic cleaning requirements.

There is normally included an attachment to fit on the exhaust side of the suction fan resulting in a "blower effect," which is extremely useful for blowing dirt out of inaccessible places such as piano interiors, corners etc.

Safety. The problem of safety to the user is linked with the more general one of whether it is better to earth or not to earth domestic appliances. Where earthing is adopted throughout a domestic installation, then vacuum cleaners should be connected to the supply outlet by 3-core flexible, all exposed metal parts of the machine liable to become live in the event of an internal fault being electrically bonded together and to the third earth wire connexion.

Probably the greater number of domestic vacuum cleaners, however, are supplied from lamp holders or two pin wall-plugs, without provision for earthing. Under these conditions there is very little risk of the user receiving a bad shock from a faulty machine when standing on the carpet or wooden floor, which are good insulators. But if, while in contact with the metal of the machine which is "live" due to a fault, the operator simultaneously makes contact with an earthed water or electric radiator or gas stove, then a very severe shock may be experienced ; fatalities have occurred under these conditions. It is, therefore, desirable that machines used on two-wire supply should have all metal parts of the machine covered with insulating protection as far as practicable. Operating handles of insulating material in place of metal (or metal tubes that are insulated from the body of the machine) are to be preferred, and rubber flexible hose is similarly safer than metallic tubing. Control switches on the machine should be of the all-insulated class, or may be of the foot-press type with which the hand does not come in contact.

Costs. The majority of domestic vacuum cleaners are driven by $\frac{1}{6}$ to $\frac{1}{8}$ h.p. motors. The consumption is thus of the order of 100 to 130 watts, corresponding to 10 or 8 hours' use per unit. Even at



VACUUM CLEANER. Fig. 3. An industrial cleaner for electrical machinery, etc.
Courtesy British Vacuum Cleaner Co., Ltd.

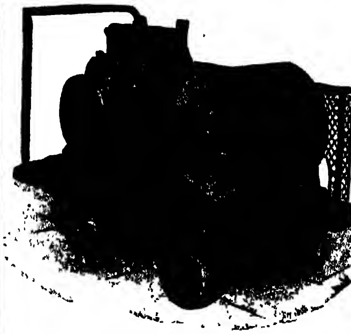


Fig. 4. A Sturtevant Turbine Type industrial cleaner.

lighting rates, this is cheap, while on domestic power tariffs regular use of the cleaner every day only entails a few pence per week for operating costs.

Machines vary very widely in first cost. The more highly priced cleaners commonly represent a standard of quality and reliability well above that of the cheapest models. There has also to be taken into account the size and speed of motor fitted. A small $\frac{1}{8}$-h.p. motor, running at 11,000 r.p.m., is obviously cheaper to manufacture than a $\frac{1}{6}$-h.p. machine running at, say, 6,000 r.p.m. Even with equally good materials and workmanship it is plain which should have the longer life and give more reliable service. In the best class machines very great care is taken in the manufacture of the motor, even down to the dynamical balancing of each individual rotor.

Faults and Repairs. The fractional h.p. motors of vacuum cleaners are liable to all the faults that may develop on larger machines—burnt-out coils, disconnected commutator segments, worn bearings, high mica, etc.—and their detection and remedy entail similar procedure to that given in other sections of this work. The most common troubles, however, are worn flexibles, dirty switch contacts, brush dust on commutators, neglect of oiling or too frequent oiling. These faults are easily discovered and simply repaired. When replacing worn brushes it is important to ensure that the right size and grade of brush is fitted, or excessive wear or heavy sparking may result.

VACUUM LAMP. *See* Lamp.

VACUUM TUBE. A glass tube made in various shapes and filled with air or gases at pressures below that of the atmosphere. The pressure in any particular tube, as the cathode ray tube, may be considerably below that of the atmosphere, *i.e.* the vacuum may be high. There are many types of vacuum tubes, the most important

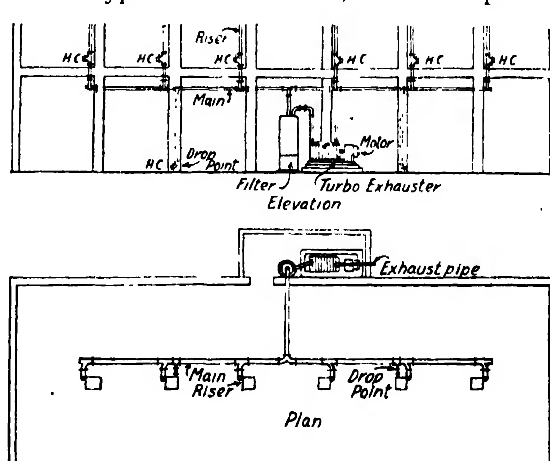


Fig. 5. Arrangement of a permanently installed central vacuum cleaning plant. H.C. indicates connexion for hose of cleaners.
Vacuum Cleaner Co., Ltd.

being described under their own headings. *See* Cathode Ray Tube; Crookes' Tube; Electron; Geissler Tube; Ultra-Violet Light; Valve.

VACUUM TUBE LAMP. The luminescent effect of the electrical discharge in a vacuum tube permits the application of such tubes to decorative lighting, illuminated signs and similar purposes as described under Gaseous Discharge Tubes, Hot Cathode Lamp, Neon Tube and Lighting, *etc.*

VALVE, THERMIONIC: BASIC PRINCIPLES AND THE MODERN TYPES

By S. O. Pearson, B.Sc., A.M.I.E.E.

This comprehensive article is in two sections. The first deals with the basic principles and characteristics of the valve used in radio communication. The second provides descriptions in alphabetical order of all the important types of valves now in use. A note on the use of the thermionic valve in H.F. induction furnaces follows as a separate article. See Amplification; Anode A.C. Resistance; Characteristic; Detector; Grid, etc.; also Broadcasting; Receiver.

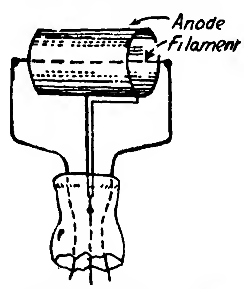
In the science of radio communication the thermionic valve, in its now numerous forms, plays a more important part than any other item in the sending or receiving apparatus. In fact, the valve constitutes the nucleus round which practically the whole of the sending and receiving circuits and equipment are designed and built. For transmitting purposes the valve is very rapidly replacing all other methods of generating high-frequency electrical oscillations.

The particular merit of the thermionic valve that puts it in a position of such pre-eminence is its property of amplifying electrical variations to an enormous degree almost without distortion, thus enabling a weak signal received by an aerial to control locally provided energy in some cases millions of times greater than that received from the transmitter.

In its strictest sense an electrical valve is a device which allows current to pass in one direction only through it, and it is on account of this property that the name "valve" has come to be applied even in cases where the device is not used in its capacity as an electrical valve. In America the thermionic valve is generally referred to as a vacuum tube.

PART I. BASIC PRINCIPLES AND CHARACTERISTICS

The Diode. In its simplest form the thermionic valve consists of an evacuated glass bulb containing an electrically heated filament surrounded by a metallic cylinder, insulated from the filament, the arrangement being shown in Fig. 1. Although this constitutes the first thermionic valve—the Fleming Valve—it is still in general use, being known as the two-electrode valve or diode. On account of its one-way conductivity it is widely used as a detector of H.F. oscillations, and as a rectifier of alternating currents. When the filament is heated to the requisite temperature by passing a current through it, a current of electricity will pass between the metal cylinder and the filament when the former is maintained at a relatively positive potential, but no current can be made to flow in the reverse direction by applying negative voltage to the cylinder, which is generally known as the anode (*q.v.*) or plate. The filament is sometimes called a directly-heated cathode, but there are types with indirectly heated cathodes (*q.v.*).

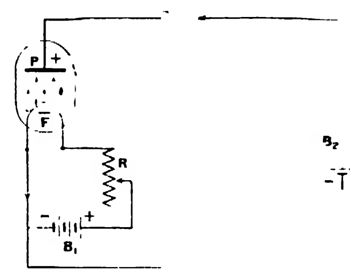


VALVE. Fig. 1. Arrangement of a diode

The ability of a current to pass between the electrodes of the valve, even when the bulb is completely evacuated, is due to a phenomenon which forms the basis of all thermionic valves. A current of electricity is a stream of electrons, and the current in the diode, passing from anode to filament according to the conventional notation of direction of flow, consists of a stream of electrons passing from the hot

filament to the relatively positive anode. This current in the vacuous space between the electrodes is called an emission current or thermionic current (*q.v.*).

The electrons are emitted by the hot filament as a result of the thermal agitation of its molecules. But for the proximity of the positive anode, these emitted electrons would fall back to the filament again. The positive potential of the anode, however, exerts an attractive force on the freed electrons and draws them across the intervening space. It should be noted that the motion of the electrons representing the current is in the opposite direction to the conventional notation of the direction of current flow.



VALVE Fig. 2 Fundamental principles of the two-electrode valve.

The maximum emission current possible depends on the temperature of the filament or cathode, the substance comprising it, and its superficial area. In modern valves the filaments are treated or coated with certain oxides such as those of barium, calcium or strontium, so that they give copious emission at relatively low temperatures compared with that required by a pure tungsten filament (*see* Thermionic Current).

Diode Characteristics. As all thermionic valves are based on the fundamental properties of the simple diode the general characteristics of the latter will be considered first. In Fig. 2 a diode is connected with a milliammeter, Ma, in the anode circuit to enable the current to be measured with various values of applied voltage for a fixed value of filament current.

The characteristic curve showing the relationship between the emission current and the anode voltage relative to the negative end of the filament is shown in Fig. 3 by the full line curve. It will be noted that there are two bends in the curve, and the reasons for these are important as they are present in all types of thermionic valves, influencing the shapes of the characteristic curves.

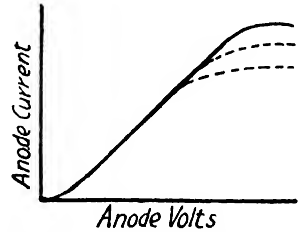
The reason for the lower bend will be considered first. It will be realized that a " cloud " of free electrons exists in the space between the filament and the anode, and as each electron constitutes a minute negative charge, the electrons in the inter-electrode space represent a negative charge of electricity. This is called the *space charge*, and is further discussed under its own heading. Now as like charges repel each other it follows that electrons which are just leaving the filament are repulsed by those already in the space between the electrodes, and there is a tendency for them to be driven back to the filament.

With low values of anode voltage the space charge drives back nearly all electrons emitted, which accounts for the comparatively gradual rise of the current curve. As the anode voltage is increased the attractive force exerted by it rises and overpowers the repelling force of the space charge to a larger extent, causing the current curve to rise.

The rounding of the curve at the bottom is also partly due to the fact that there is a potential rise along the filament from the negative end, the anode voltage being therefore less positive with respect to the positive end of the filament than the negative end. With an indirectly heated cathode (*q.v.*) where the whole of its surface is at the same potential, this effect is absent and the lower bend of the characteristic curve is very much sharper. This is an important point, when a diode is used as a linear rectifier, for giving distortionless rectification.

Saturation. The main portion of the curve is comparatively straight, but as the anode voltage is progressively raised the current eventually reaches a constant maximum value, when the valve is said to be saturated. This occurs when the maximum number of electrons per second that the filament can emit at the given temperature are all attracted to the anode. The saturation current depends to a very critical degree on the filament temperature —a small decrease of filament current results in a comparatively large decrease in maximum emission current. The effect of reducing the filament current in successive stages is shown by the dotted line curves of Fig. 3.

The Three-Electrode Valve. The two-electrode valve is useful only in respect of its rectifying properties, and to some extent the saturation conditions; it possesses no amplifying powers. In the three-electrode valve or triode a grid or wire mesh is interposed between the filament (or cathode) and the anode with the object of controlling the stream of electrons. The grid and anode are insulated, from each other and brought out to separate pins in the valve base. The action of the grid is to modify the effect of the space charge according to the applied potential with respect to the cathode. For instance, in a diode the potential at a distance of, say, 2 millimetres from the filament might be -10 volts. Suppose now that the filament is surrounded by an open wire helix 2 mm. in radius, and its potential made -5 volts with respect to the negative end of the filament. It will naturally weaken the negative field due to the space charge there, and allow more electrons to be drawn off from the filament, so increasing the anode current.



VALVE Fig. 3. Characteristic curve of a diode

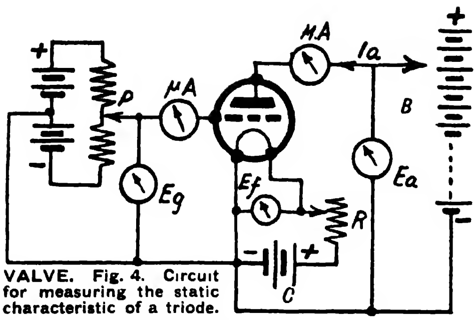
This third electrode is called the grid of the valve; it must necessarily be in the form of an open mesh or spiral so that the electrons issuing from the filament can pass through the interstices and reach the anode, or "plate" as it is sometimes called. When the grid is negative with respect to the filament it has no attraction for the free electrons, which pass through without adhering to it, so that no "grid current" flows. However, if the grid is made positive with respect to the filament it attracts electrons to it, acting itself like an auxiliary anode, and grid current does pass. These conditions play an important part in operation and will be referred to again.

General Properties of the Triode. The characteristics of the valve depend to a very large measure on the geometrical arrangement of the electrodes and a great many designs are to be found among modern valves. Some types, for instance, have a filament in the form of an inverted V, or an N or M shaped one surrounded by a flat-shaped grid and anode. The general design is governed by the purpose for which the valve is to be used, and the conditions under which it is to be operated. As the applications of valves in modern radio apparatus are very numerous indeed, it is not surprising that there should be a great variety of designs on the market. The technique of valve design is a science in itself.

The triode may be looked upon as the parent of all types of amplifying valves—screen-grid valves, pentodes, etc., have all been evolved from the triode, and for this reason a knowledge of the basic principle of the triode is essential if the action of the more complicated special valves is to be understood. When the filament or cathode of a triode is heated to the normal operating temperature and a specified positive voltage is applied to the anode, the value of the anode current depends on the potential applied to the grid. If the grid potential is varied, the anode current changes. On the other hand, if the grid potential is kept constant the anode current will vary with change of anode voltage. Thus there are two ways of varying the anode current and it is the relationship between these two processes that determines the essential properties of the valve.

Anode and Grid Characteristics. The performance of a triode can be accurately predetermined from curves of anode current plotted against anode voltage with a fixed grid potential on the one hand, and of anode current plotted against grid voltage with fixed anode potential on the other. Such curves are called static characteristics; they are supplied by the manufacturers with each valve. A circuit for obtaining them by measurement is given in Fig. 4. The instruments must be in the positions shown so that the currents taken by the voltmeters do not affect the milliammeter readings. In any case high-resistance voltmeters should be used, and special instruments designed for this purpose are to be found on the market.

In the first place the filament (or heater, if the valve is an indirectly heated one) voltage is adjusted to the correct value



VALVE. Fig. 4. Circuit for measuring the static characteristic of a triode.

by the resistance R. By means of the grid battery C and the potentiometer resistance P, the grid voltage can be varied over a range of positive and negative values. The anode voltage is varied in steps by changing the tapping points to the high-tension battery B. To obtain the anode-voltage/anode-current curve for any one value of grid voltage, set the slider P until the voltmeter E_g indicates the required grid voltage, say zero to begin with. Then take corresponding pairs of readings of the anode current I_a and anode voltage E_a for different tapping points on the H.T. battery B, and plot the readings as a graph. Further sets of readings may be obtained for different values of E_g, and the curves plotted.

On drawing the curves it will be found that the shape of each is very similar to the characteristic curve of a diode, a typical set of curves for a certain type of valve being shown in Fig. 5. It should be noted that the curves are parallel over the straight portions and that one volt increase of negative grid bias moves the curve 35 volts to the right in this case. Under normal operating conditions the anode current contains an alternating component, and from the particular curve of Fig. 5 corresponding to the normal grid potential, the internal resistance offered to the alternating component of current can be found. It is represented by the slope of the curve and the method of finding it is explained under the heading Anode A.C. Resistance.

The next important characteristic curves to be found are those showing how the anode current depends on the grid voltage, the anode potential being kept constant. Referring again to Fig. 4 the filament voltage and the anode voltage are adjusted to the correct values. Then readings of the anode milliameter are taken for various values of grid-voltage E_g adjusted by means of the potentiometer P. During the taking of one set of readings E_a and E_f must be kept constant, but further sets of readings can be obtained with other fixed values of anode voltage. There is a separate grid voltage/anode-current characteristic curve for each value of anode potential, so that the number of curves obtainable is unlimited.

A number of grid characteristic curves are given in Fig. 6 for the same valve to which Fig. 5 refers—an indirectly heated cathode amplifying triode designed for an anode voltage not exceeding 200. From Fig. 6 it will be noted that when the grid voltage is highly negative with respect to the cathode no anode current flows, but as the negative grid voltage is decreased towards zero—that is, as the voltage is changed in the positive direction—the anode current starts at some particular value of grid voltage and increases, gradually at first, and then more rapidly until the steepest part of the curve is reached. The curves are practically straight and parallel to each other over their steepest portions, this being a necessary condition in distortionless amplification.

The slope of the grid-volts/anode-current curves in conjunction with the anode A.C. resistance determine the performance of the valve as an amplifier.

The slope is referred to as the mutual A.C. conductance and is discussed under its own separate heading (*q.v.*).

Grid Current. An important feature of the triode is that, provided the grid is negative with respect to the cathode, no current will flow in the grid circuit, this

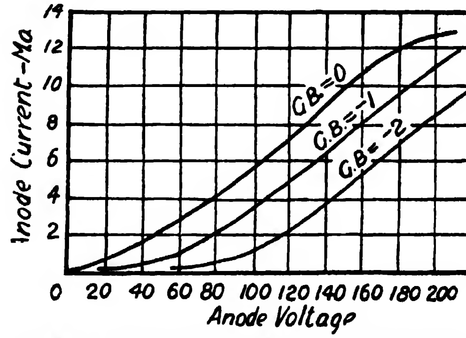
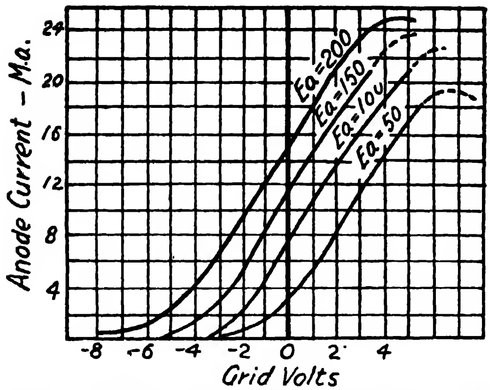


Fig. 5. Anode-voltage/anode-current characteristics of a general purpose triode, with grid bias.



VALVE. Fig. 6. Grid-voltage/anode-current curves for a triode amplifying valve.
Courtesy of "The Wireless World."

being a matter of great importance under operating conditions. When the grid becomes positive it attracts electrons to it and grid current flows; with a high positive potential on the grid a large proportion of the electrons may be intercepted in this way so that the anode current is reduced again (*see* 50-volt curve of Fig. 6). In nearly all circumstances grid current is undesirable and so we are mainly concerned with the portions of the curves of Fig. 6 which fall to the left or negative side of the origin.

The Valve as Amplifier. The ability of a valve to amplify weak electrical variations is its main attribute. Amplification is possible at any frequency, high or low, but amplifying valves are designed to have characteristics specially suited to the conditions of operation. The amplifying properties arise because a small change of grid voltage has the same effect on the anode current as a relatively large change of anode voltage. For a valve to act as an amplifier some form of impedance must be connected in the anode circuit (*see* High-Frequency Amplification *and* Low-Frequency Amplification). Then, providing this impedance is not small compared with the valve anode A.C. resistance, a small change of grid potential produces a relatively large change of voltage across the impedance connected in the anode circuit, the ratio of the latter to the former being the voltage amplification or stage gain.

The action of the valve as amplifier is made clear by the composite diagram of Fig. 7, the characteristic curve being one of those given in Fig. 6 for an actual valve. To begin with, the grid voltage is fixed at -2 volts, this being the "grid bias" (*q.v.*). Then, after a short interval of time, the grid voltage is made to vary periodically by one volt above and below the mean value, as shown in the bottom left of the diagram, the anode voltage being maintained constant. From the constructional lines it will be evident that the variations of grid voltage produce corresponding variations of anode current; if the grid voltage variation is a sine wave, the resulting anode current variation will be a sine wave also *provided the operating portion of the characteristic curve is straight.* This is substantially true for small variations.

Amplification Factor. It has already been explained that the anode current can be varied by changing either the grid voltage or the anode voltage. Consequently, an alternating voltage applied to the grid has the same effect as a larger value of alternating voltage in series with the anode circuit. When the grid voltage changes from -1 to -3 volts, as in Fig. 7, the resulting anode current is seen to change from 11·6 mA. to 6 mA., so that two volts variation at the grid gives 5·6 mA. variation of anode current. Now, from Fig. 5, which refers to the same valve, the change of *anode* voltage required to produce 5·6 mA. change of current is about 72 volts, the anode A.C. resistance being therefore $\frac{72}{5{\cdot}6} \times 1{,}000 = 12{,}900$ ohms approximately. It also follows that 72 volts change at the anode has the same effect as

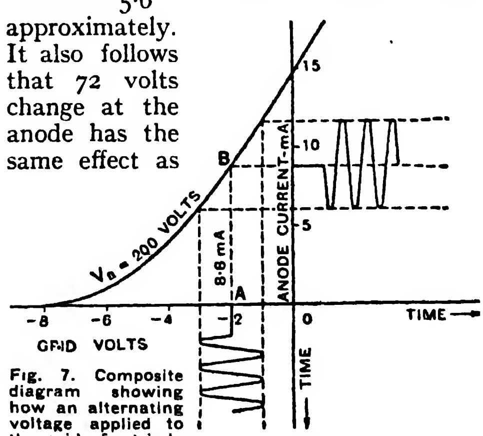


Fig. 7. Composite diagram showing how an alternating voltage applied to the grid of a triode produces an alternating component of current in the anode circuit.
Courtesy of "The Wireless World"

two volts change at the grid, and the ratio of these is called the Amplification Factor or Amplification Constant of the valve, being in this case 36.

The amplification factor is defined as the ratio of the change of anode voltage to the change of grid voltage required to bring about the same small change of anode current, and it is usually denoted by the Greek letter μ. So when a small alternating voltage E_g is applied to the grid a larger voltage μE_g is, in effect, injected into the anode circuit and drives an alternating component of current round the latter, this being additional to the steady direct current produced by the H.T. battery. When no impedance is connected in the external anode circuit the alternating component of the anode current is given by Ohm's law, namely $I_a = \frac{\mu E_g}{R_a}$ ampères, where R_a is the internal anode A.C. resistance as already defined.

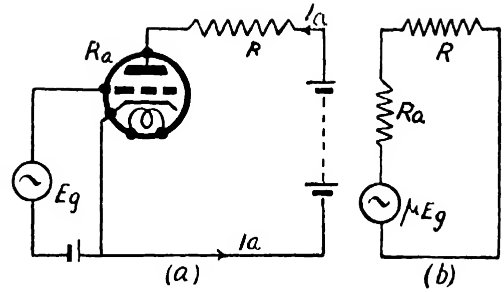
Another important constant of the valve is the mutual A.C. conductance which is defined as the ratio of the A.C. component of the anode current (with no external impedance) to the alternating voltage applied to the grid. For the valve considered it is $\frac{5·6}{2}$ = 2·8 milliamps. per volt.

It is also numerically equal to the ratio $\frac{\mu}{R_a}$ being $\frac{36}{12000}$ = 0·0028 amps. per volt, or 2·8 milliamps. per volt.

Valves can be constructed with any desired amplification factor, since the problem of design is largely one in electrostatics and the voltage amplifying property gives a clue to the use to which the valve should be put. A high μ factor denotes the suitability of the valve for use as a radio-frequency amplifier or detector, whereas a low μ restricts a valve to audio-output stages.

In practice, the actual amplification seldom reaches the value of μ, although values 75 per cent. of μ are easily secured. Maximum power output is obtained when the valve A.C. resistance equals the plate circuit resistance, although if this latter value is not variable, valve A.C. resistance (R_a) should be greater than external load (R).

Conditions for Amplification. For the valve to act as an amplifier of small alter-



VALVE. Fig. 8. (*a*) A triode with resistance R in the anode circuit. (*b*) Equivalent circuit relating to A.C. components only in the anode circuit. The voltage amplification obtained is $\frac{\mu R}{R + R_a}$, the amplified voltage appearing across R.

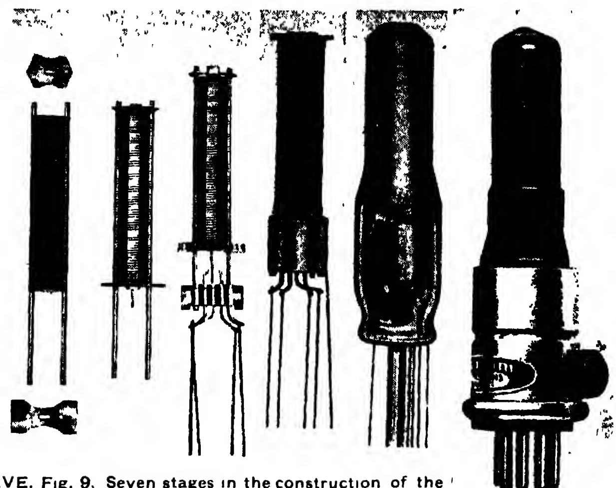
nating voltages an external impedance must be connected in the anode circuit so that the alternating current produced by the grid voltage variations sets up an alternating potential difference between the ends of the added impedance. This constitutes the amplified voltage, and its value can be calculated when the valve constants and the value of the impedance are known. In Fig. 8 (*a*) the added anode impedance is in the form of a resistance R, which gives the simplest case. When only A.C. components are considered the circuit becomes equivalent to that shown at (*b*) in Fig. 8, which lends itself to easy treatment. μE_g represents the alternating E.M.F. injected into the anode circuit by the action of the grid. The total resistance of the circuit is $R + R_a$ and so the current is $I_a = \mu E_g/(R + R_a)$ ampères. This current in R sets up across the latter a potential difference $I_aR = \mu E_g \frac{R}{R + R_a}$ which is the amplified output voltage. The ratio of this to the original voltage E_g at the grid is $\mu \frac{R}{R + R_a}$ which is the number of times the applied voltage is multiplied. When the resistance R in Fig. 8 is replaced by a choke coil of reactance X ohms the voltage amplification becomes $\mu \frac{X}{\sqrt{R_a^2 + X^2}}$.

The foregoing gives an outline of the basic principles upon which the amplifying properties of a valve depend. The various methods of applying these principles in practice are dealt with in separate articles and entries to which the reader is referred. These include: High-Frequency Amplification; Low-Frequency Amplification; Resistance-Capacity Coupling; Choke-

Capacity Coupling ; Tuned-Anode Coupling ; *etc.*

The usefulness of the triode is not confined only to amplification but extends to a variety of other purposes, chief among these being its use as a detector of high-frequency oscillations in different ways. As this subject is fully dealt with under the heading Detector, Anode Bend Rectification, and Grid Rectification, no further reference is needed here.

Another important function is the generation of oscillations, for which see Oscillator ; Regeneration.



VALVE. Fig. 9. Seven stages in the construction of the "Catkin" valve. A sectional drawing and complete view of another type are given below.

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PART II. TYPES OF VALVES

As previously mentioned, there are many varieties and types of thermionic valve designed to suit the needs of special conditions and having special characteristics or constructional features. The different types are given in this section in alphabetical order according to the usual names by which they are known. Where an independent entry is made elsewhere the necessary reference is given.

A.C. Valve. *See* Indirectly Heated Valve, *below*.

Bigrid Valve. A valve with two control grids, one of the main applications being the simultaneous amplification of H.F. and L.F. signals in reflex circuits. The signal oscillations are applied to one of the grids, amplified and passed on to the detector. The L.F. output from the detector is then fed back to the second grid and amplified by the bigrid valve, the H.F. and L.F. variations in the anode circuit being separated by suitable filter circuits. *See* Screen Grid Valve.

Catkin Valve. A type of receiving valve with very special features of construction developed by the Marconi-Osram Valve Company, Ltd. The object of the design is robustness and constancy of characteristics.

The main feature of the construction as far as outward appearance is concerned is the replacement of the usual glass bulb by a metal cylinder which actually comprises the anode. This principle has been used for large transmitting valves for many years, being known as "cooled

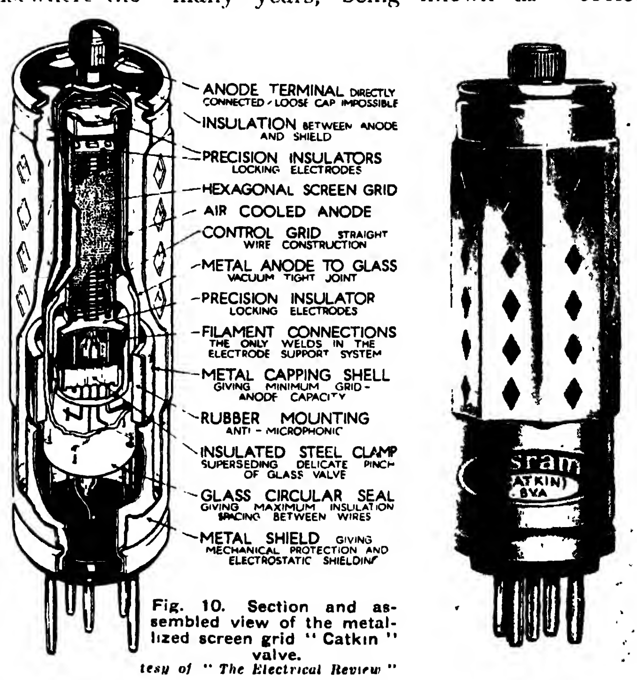


Fig. 10. Section and assembled view of the metallized screen grid "Catkin" valve.

tesy of " The Electrical Review "

anode transmitters," and abbreviated C.A.T. from which the name "Catkin" is derived for the corresponding type of receiving valve. The cylindrical anode is made of copper and a gas-tight copper-to-glass seal is made at the lower end of the anode. The details of construction are shown in Figs. 9 and 10.

Not only are the design and construction of the envelope of the Catkin valve different from conventional methods; the internal arrangements and supports of the electrodes are also unique. The usual glass "pinch" is abolished, the electrode supports being held in a mica clamp. As the ordinary glass "pinch" is a source of considerable dielectric loss at radio frequencies the Catkin construction represents a marked improvement in operating efficiency. The leads do actually pass through a glass ring at the base of the valve, but they are disposed round the circumference, giving very small capacity.

The electrode supports are straight, stiff wires free from bends and welds, with the result that the spacing between the electrodes can be accurately adjusted, and these adjustments will be permanent. Consequently much greater uniformity as regards operating characteristics is possible with the Catkin construction. The rigidity of the whole construction is such that it is very difficult to damage a valve. It is claimed that a Catkin valve may be dropped on to a concrete floor from a height of several feet without damage.

A protective metal outer cover is provided, as the anode is at high positive potential with respect to earth under operating conditions.

Class "B" Valve. An output valve specially designed for Class "B" amplification (*q.v.*). It consists essentially of two matched triodes enclosed in a single bulb and operated in push-pull. It is designed for operation with either zero or very small grid bias so that grid current flows in each grid circuit during positive half cycles of the input voltage. The type is meant for use in battery-operated receivers, giving a large output with extreme economy in H.T. current consumption.

As grid current flows the input impedance is low, and for this reason it is fed from the preceding L.F. stage through a one-to-one or a step-down transformer, usually referred to as the "driver" transformer, as there is a power output from the secondary circuit. The principles of Class "B" amplification are given in an independent entry.

Diode. A two-electrode valve possessing anode and filament (or cathode) only. Although this was the first type of thermionic valve to be developed it is widely used to the present day for various purposes, among them being (a) rectification of alternating currents (rectifying valves), as in battery eliminators; (b) detection of H.F. oscillations in receivers (*see* Detector); (c) automatic volume control. The use of a diode as detector has the advantages of linear rectification and the capability of handling signal voltage inputs of high amplitude without overloading.

Double-Diode. A valve with two anodes operating on the diode principle used in connexion with automatic volume control, where a single valve acts simultaneously as detector and volume control. *See* Automatic Volume Control.

Double-Diode-Pentode. A pentode valve based on the same principles as the double diode triode, having two auxiliary anodes. The pentode portion is usually of the variable-*mu* type, enabling an increased degree of automatic volume control to be obtained.

Double-Diode-Triode. A triode valve provided with two extra auxiliary anodes, developed for providing amplified automatic volume control. For details of operation, *see* Automatic Volume Control.

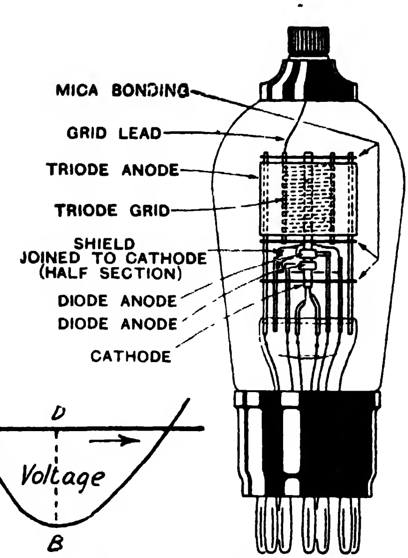
Dynatron Valve. A form of three-electrode valve where use is made of the emission of secondary electrons from the anode due to violent bombardment by the electrons coming from the cathode. The special operating condition is that the grid is given a positive potential higher than that of the plate, so that the secondary electrons emitted by the plate are attracted to the relatively positive grid. These secondary electrons represent reverse current, and so reduce the total anode current below the figure which would be obtained if there were no secondary emission.

In certain circumstances the number of secondary electrons freed per second from the plate may be actually greater than the

number reaching it from the cathode, and the anode current is· actually reversed. The effect is indicated by the curve in Fig. 12 ; this shows how the current varies as the anode voltage is raised, the grid voltage being kept at a constant high positive potential. The circuit arrangement is shown as inset.

The fact that the anode current becomes more negative from A to B on the curve as the anode voltage is increased positively from C to D shows that a "negative resistance" effect is brought into play. A circuit possessing this negative resistance effect is unstable, and the device is used for the generation of electrical oscillations, among other purposes. Almost any ordinary triode will act as a dynatron.

Fig. 11



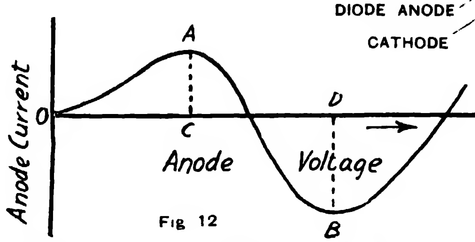


Fig 12

VALVE Fig. 11. The electrode arrangement of the Osram double-diode-triode The grid connexion is at the top and the other electrodes brought out to a standardized 7-pin base. Fig. 12. Characteristic curve for a dynatron Between C and D the anode current becomes more negative as the anode voltage is increased positively.

Courtesy of "The Wireless World"

Electron Valve. A vacuum tube in which the current passing between the electrodes is represented by a stream of free electrons, *e.g.* a thermionic valve.

Five-Electrode Valve. *See* Pentode, *below*.

Four-Electrode Valve. *See* Bigrid, *above*, and Tetrode, *below*.

Hard Valve. A valve in which every possible trace of gas is removed from the bulb. The life of the valve and the constancy of its characteristics are greatly influenced by the "hardness." Modern receiving valves are all hard valves.

Indirectly-Heated Valve. A valve in which the cathode is heated by a current passed through an entirely separate heater element, thus enabling alternating current or current from D.C. mains to be used for heating purposes, without interfering with the performance of the valve. The standard heater voltage for A.C. valves is 4, but indirectly heated valves for D.C. operation have heater voltages varying between 16 and 40. For details of construction *see* Indirectly Heated Cathode.

Ionic Valve. A valve in which traces of gas are left in the bulb, for instance a "soft" valve. The gas becomes ionized and current is passed between the electrodes by conduction through the gas. The ionization is produced by electrons colliding with gas molecules.

Kenotron. A diode rectifying valve designed for operation at high voltage, as in transmitting apparatus, the bulb being highly evacuated.

Pentode Valve. A valve with five electrodes, namely anode, cathode and three grids. The grid nearest the cathode is the control grid corresponding to the grid of a triode and to which the signal voltage is applied. The intermediate grid is maintained at a constant positive potential, and acts in the same capacity as the screen grid in an ordinary screen-grid H.F. valve. The grid nearest the anode is joined internally to the cathode, and its purpose is to eliminate the negative resistance kink which is always present in the anode voltage/anode current characteristic of the ordinary tetrode or screen grid

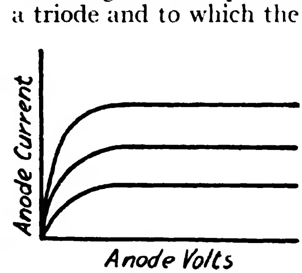


Fig. 13. Characteristics of a screened H.F. pentode for different values of grid bias. Note the absence of the negative resistance kink compared with screen grid valve curve.

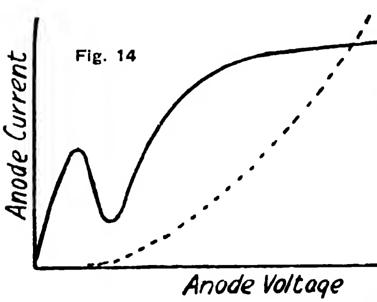
valve. The advantage of the pentode as an output valve is its high efficiency—details will be found in the independent entry under Pentode. Screened pentodes are also available for H.F. amplification and possess considerable advantages over the tetrode due to the absence of the negative kink in the characteristic curve. Typical characteristic curves for a screened H.F. pentode are given in Fig. 13.

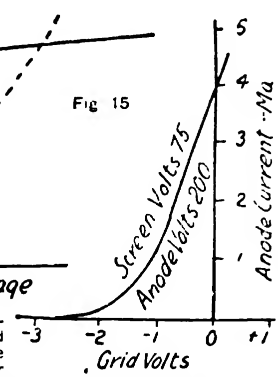
Power Valve. A valve (usually triode) designed to give a large output for use in a power amplifier, *i.e.* one where large voltage amplitudes have to be dealt with. The special features are high anode current at moderate anode voltages, and the operating characteristic curves must be as straight as possible over a wide range to give distortionless amplification. An output triode comes within this category when the maximum undistorted output is up to 500 milliwatts or so, or the A.C. resistance is less than 7,000 ohms. Those giving higher outputs are sometimes known as super-power valves.

Rectifying Valve. A diode valve used for rectifying alternating currents, as for example in H.T. battery eliminators. The particular features are high emission current and low internal impedance. A single diode gives half-wave rectification, only the positive half waves of current being passed. Full-wave rectifier valves are provided with two anodes and sometimes two filaments or cathodes.

Screen Grid Valve. A tetrode or four-electrode valve designed originally for giving stable H.F. amplification without special neutralizing circuits (*see* Neutrodyne). As a high-frequency amplifier the triode possesses the disadvantage that the anode-to-grid inter-electrode capacity tends to produce instability, and the screen grid valve has been developed to overcome this difficulty. A special screening grid introduced between the control grid and the anode shields the former from the effects of voltage variations at the anode, the screen being maintained at a constant positive potential somewhat less than the mean anode potential. The effective residual capacity is thus reduced to a sufficiently low figure to render stable operation of the valve possible.

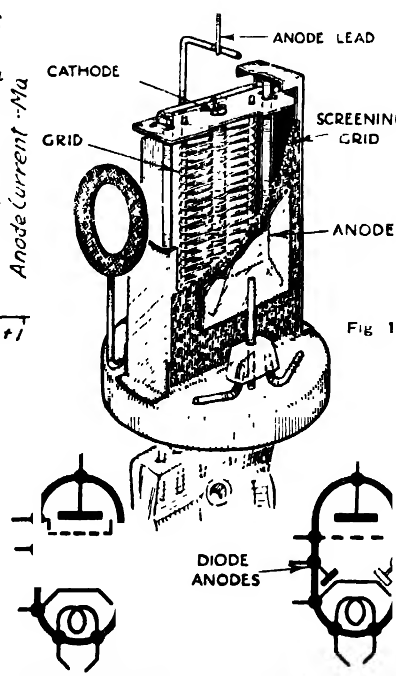
The form of the anode characteristic curves is considerably modified by the introduction of the screen grid compared with a triode, the relative forms for the two types being shown in the diagram of Fig. 14. It will be noted that a kink occurs near the lower end of the screen grid curve and that for higher anode voltages the anode current becomes almost constant. The dip in the curve is due to the emission of secondary electrons from the anode and their collection by the relatively





VALVE. Fig. 14. Screen grid, anode-voltage/anode-current with fixed screen voltage and grid bias. The dotted line is a triode curve for comparison. Fig. 15. Grid-voltage/anode-current curve for screen grid valve. Fig. 16. Construction of a screen grid valve and arrangement of electrodes.

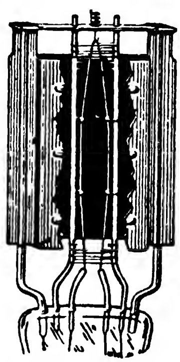
Fig 16 By courtesy of "The Wireless World"



positive screen grid. (*See* Dynatron, *above.*)

The grid-voltage/anode-current characteristic curve is of the same form as for a triode, but the curvature at the lower bend is particularly sharp and the permissible swing of grid voltage is very limited (*see* Fig. 15). These shortcomings frequently result in the form of interference known as cross modulation (*q.v.*), and modifications in design to eliminate this effect have resulted in the evolution of the variable-*mu* valve, which is of the screen-grid type and now universally employed for H.F. amplification. *See* Variable-*Mu* Valve *below* for details.

Screen grid valves are characterized by exceptionally high amplification factor and A.C. anode resistance.



VALVE. Fig. 17 A "Cossor" battery triode. Note the mica bridge ensuring consistent characteristics, and the seven-point filament suspension to prevent microphonic noise.

Super-Power Valve. The name sometimes applied to a receiving triode capable of an undistorted output of one watt or more. The amplification factor and anode A.C. resistance are comparatively low. The name is becoming less generally used than previously, as output valves are now listed and rated according to the maximum undistorted output.

Tetrode. A four-electrode valve. Within this category are screen grid valves, *which see. See also* Variable-*Mu* Valve, *below.*

Three-Electrode Valve. The triode. *See* Valve—Part I for full details and general principles.

Three-in-One Valve. An arrangement in which the elements of three triodes are enclosed in a single bulb, complete with inter-valve couplings of the resistance-capacity type. An example is the Loewe valve.

Transmitting Valve. The basic principles underlying the action of transmitting valves are identically the same as for receiving valves, but transmitting valves differ considerably in design and construction, for they are operated under totally different conditions. Whereas the power associated with a receiving valve

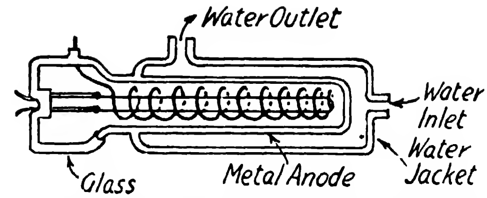


Fig. 18. Section of a high-powered water-cooled transmitting valve.

is reckoned in milliwatts, individual transmitting valves may be rated in terms of anode power dissipation, at anything from a few watts to many kilowatts, and correspondingly high anode voltages are used.

Thus the two main factors governing the design of high-power transmitting valves are the high voltages used and the power to be dissipated at the anode, the corresponding problems being respectively insulation and hardness on the one hand and facilities for cooling the anode on the other. As the working conditions are severe, every possible trace of gas is removed from the bulb, evacuation being carried to the highest possible degree.

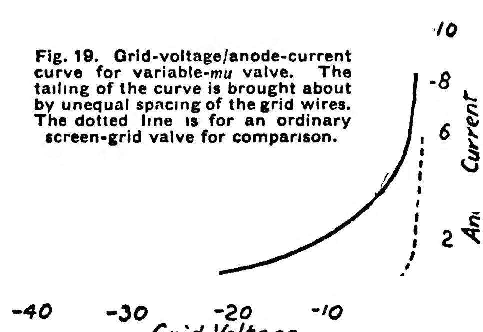
In large transmitting valves the anode is usually water-cooled, a system calling for special construction. The basis of such a design is indicated in Fig. 18 where the anode itself forms part of the envelope and also the inner wall of the water-jacket.

Two-Electrode Valve. *See* Diode *and* Rectifying Valve.

Vacuum Valve. An alternative name for Thermionic Valve.

Variable-*Mu* Valve. An important class of high-frequency amplifying valve of the screen grid type in which the amplification factor, denoted by the Greek letter μ (pronounced "*mu*"), can be varied by

Fig. 19. Grid-voltage/anode-current curve for variable-*mu* valve. The tailing of the curve is brought about by unequal spacing of the grid wires. The dotted line is for an ordinary screen-grid valve for comparison.



changing the negative grid bias. The valve is designed so that the grid-voltage/anode-current characteristic curve tails off gradually to the left as the negative grid voltage is increased, as indicated by the full-line curve in Fig. 19. The broken-line curve is that of an ordinary screen grid valve, included for comparison.

The outstanding advantages of the variable-*mu* type are (a) that the degree of H.F. amplification given can be adjusted merely by altering the grid bias, thus providing a simple and very effective means of obtaining volume control; (b) comparatively large signal amplitude can be handled without cross-modulation (*q.v.*) occurring. *See* Screen Grid Valve.

Variable-*Mu* Pentode. A variable-*mu* valve of the screened pentode class, the outstanding feature of which is the absence of the negative resistance kink in the anode characteristic curves common to screen grid tetrodes. It is a high-frequency amplifying valve capable of handling more powerful signals than the tetrode. *See* Pentode, *above*.

VALVE, THERMIONIC: in H.F. Furnaces. The thermionic valve type furnace is the most flexible of the high-frequency induction furnaces on the market, and is extensively used for research work when working with rare or costly metals, and in applications where it is desirable to provide such a frequency as will melt all charges from a few grammes to the maximum capacity of the furnace. The smaller the charge and the greater the resistivity the higher is the frequency that must be employed. Thus, while a ¼-ton charge of steel can be melted with a frequency of 500, to melt a few grammes of steel a frequency of something nearer a million periods is necessary. This range of frequencies is achieved by the employment of thermionic valve oscillators.

The oscillator valve commonly adopted has the customary three electrodes, the anode consisting of a copper cylinder surrounded by a water-jacket and sealed to a glass chamber which serves to bring in the leads and support the grid and filament. The grid is in the form of a wire helix surrounding the tungsten filament.

VARIABLE CONDENSER. *See* Condenser (in Radio).

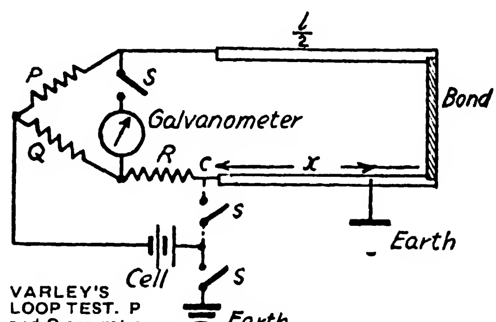
VARIABLE COUPLING. *See* Coupling of Circuits *and* Loose Coupling.

VARIABLE VOLTAGE CONTROL. *See* Ward-Leonard Control.

VARIATION. The angle which the compass needle makes with the geographical north and south meridian. Sometimes termed the Declination, this angle varies for different parts of the earth.

The expression is also applied to the maximum deviation from synchronism, in electrical degrees, occurring in an alternator coupled to an engine of unequal turning moment, due to the cyclic irregularity (*q.v.*) or to the angular displacement of the rotor under these conditions in degrees.

VARLEY'S LOOP TEST. A method of fault location on the Wheatstone Bridge principle, adopted where an earth occurs



VARLEY'S LOOP TEST. P and Q are ratio arms of P.O. bridge. R is resistance; *l*, total length of cable; S, switches; and *x*, the unknown distance of fault.

on a main and a loop can be made by connecting the far end of the main to another main returning to the station. The connexions are illustrated in the diagram and the method involves two tests, one with a resistance inserted in series with the faulty main, and the other for measuring the total line resistance. A Post Office bridge (*q.v.*) is conveniently employed for this purpose, and the insert resistance R is adjusted until zero deflection is obtained. For the second test the earthed pole of the battery is disconnected from earth and joined to the insert resistance as indicated at C. Then

$$\frac{\text{line resistance (r)}}{\text{R}} = \frac{\text{P}}{\text{Q}}$$

for zero deflection, where P and Q are

known ratio arms of the P.O. bridge. The distance x of fault from C equals

$$\frac{l(rQ-PR)}{r(P+Q)}$$

where l is total length of cable. *See* Test.

VARNISH, INSULATING. *See* Insulating Varnishes.

" V " CONNEXION. When one side of a mesh-connected three-phase transformer set is removed, the other two sides, remaining connected to three-phase mains, will continue to handle the load, the full-load capacity being reduced by one third. The method is known as " open-mesh " or " V " connexion. It does not often occur in practice, but when so occurring can be treated for paralleling in the same way as " mesh "-connected banks of transformers. *See* Mesh Connexion ; Star Connexion ; Transformer.

V.D.E. RULES. These rules are established by the Verband Deutscher Elektrotechniker E.V. and published as the " Vorschriftenbuch des Verbandes Deutscher Elektrotechniker " by the same society in Berlin-Charlottenburg 4, Bismarckstrasse 33, from whom they may be obtained. In the latest edition the rules are contained in a book of over 1,200 pages.

The rules cover every field of electrical engineering and constitute the German equivalent of the B.S.I. specifications and the Regulations of the Institution of Electrical Engineers in Great Britain.

The provisions of the rules are divided in four classes. First there are Prescriptions (Vorschriften), which are framed with a view to preventing risk of accident and fire and which are compulsory.

Second there are Rules (Regeln) which deal either with the manner in which the prescriptions are to be carried out or precautions which are to be respected in the same way as prescriptions unless in a particular case a special reason for not doing so is present.

The third category is that of Recommendations (Leitstätze) which are measures which it is intended to issue sooner or later in the form of Prescriptions or Rules and the observation of which is advised.

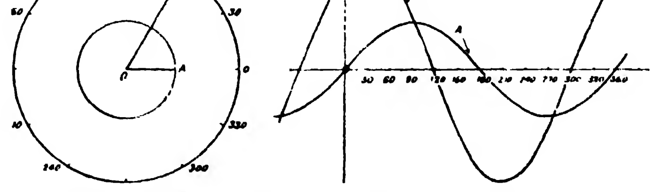
Finally, there are the Standards (Normen) which give exact particulars of standard shapes, sizes, constructions, materials, weights and mechanical and electrical properties in general, which should be observed in the manufacture of electrical apparatus.

The greater part of the Standards have been prepared in collaboration with the German Standards Committee (Deutscher Normenausschuss), and appear not in the Vorschriftenbuch but in form of "Deutsche Industrienormen " ; they are characterized by the initials " VDE.DIN," and may be obtained from Messrs. Beuth-Verlag A.G. Berlin SW 19, Dresdenerstrasse 97.

VECTOR. It is shown in the article on sine curve (*q.v.*) that this curve can be represented as the result of the movement of a point round the circumference of a circle. If another point moves round the circumference of another circle it also produces a sine curve. As long as both points take the same time to get round, both curves have the same period. If the radii of the two circles differ they have different amplitudes. The two points need not start off from the same place at the same moment.

For instance, in Fig. 1, point B moving round the larger circle counterclockwise is 60° ahead of A on the smaller. As both get round in the same time it is always 60° ahead. It is said to be 60° *out of phase* and leading. If A and B started off together they would be *in phase*. If B were behind A it would be called *lagging*. If the two are 90° out of phase they are said to be "in quadrature." The curves corresponding to the movement of points A and B are shown on the figure.

It often happens that two or more things vary according to a sine law and

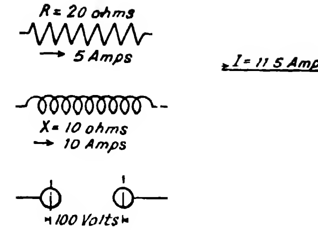


VECTOR. Fig. 1. Sine curves of two vectors with a phase displacement of 60°.

with the same frequency, but with different phase and amplitude. When a pendulum swings, for instance, its weight moves according to a sine curve. The amplitude is the farthest position it reaches. When it gets there it is just turning round and its speed is zero. When it is in the middle of its swing the sine curve representing its position is zero, but its speed is a maximum. It can be shown that the speed also varies according to a sine law. But it is zero when the swing is greatest, and greatest when the swing is zero. The speed is said to be 90° out of phase with the position of the weight.

Vectors as Mathematical Short Cuts. An alternating electric current or voltage follows a sine law. Any current may be out of phase with the voltage producing it. Thus the two curves in Fig. 1 might represent a current A lagging 60° behind its voltage B. Sometimes many currents and voltages have to be considered in a complicated circuit. When the current passes through a reactance it lags 90° behind the voltage, in a capacity it is 90° leading and in a resistance it is in phase. Thus each current and voltage may be displaced. Each could be drawn as a sine curve. The result would be a tangle difficult to draw and almost impossible to understand. It is far simpler merely to draw the line from the centre of the circle to the circumference such as the lines OA and OB. It is not necessary to draw the circles themselves. It is understood that these have O for centre and pass through the points A and B. Thus two simple straight lines OA and OB are all that is needed to convey the same message as the two sine curves at the right of the figure. These lines are called vectors. Their lengths give the amplitudes of the sine curves, their relative directions the phase displacement between them. Vectors are, therefore, mathematical short cuts.

Voltage and Current Relations. They constitute a very convenient way of representing the relation between alternating voltages and currents. For instance, let OA be the vector of a voltage in one conductor and OB that of the voltage in another. We want to know what will happen if the terminals of the two conductors are connected together. The diagram tells us. Between the terminals



VECTOR. Fig. 2. Circuit diagram of resistance R and reactance X in parallel.

is an alternating voltage. When the voltage represented by vectors OA and OB are equal this is zero. This refers to the points where the two sine curves cross. It reaches a maximum when the two sine curves are farthest apart. It can be shown that it is correctly represented by the line AB. This is its vector. As the triangle OAB rotates about O, the voltage between the two conductors is zero when AB is horizontal and is a positive or negative maximum when AB is vertical.

In this way the effect of combining any number of currents and voltages can be found quickly by drawing the straight lines representing their vectors. Consider, for instance, Fig. 2. 100 volts is supposed to be applied to a resistance and a self-induction in parallel. The current in the resistance reaches its maximum value at the same moment as the voltage, that in the self-induction when the voltage is zero. The two currents can therefore be represented by the two vectors OR and OX in Fig. 3. The current I to which they combine is represented by the vector RX. It can be measured off if the vectors are drawn to scale and is found to be 11·5 amps.

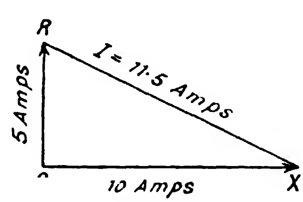


Fig. 3. Vector diagram for conditions given in Fig. 2.

When two alternating currents are to be switched together they must not only be equal in magnitude but their vectors must also coincide. This is often expressed by saying that they must be in phase. If they are not there will be a voltage between them which will cause a sudden rush of current on switching. For this reason synchronizing gear is provided on switchboards which enables the attendant to

make sure that the three necessary switching conditions are fulfilled, namely equal voltages, equal frequency and equal phase of the two supplies to be paralleled. These conditions can be briefly expressed by saying that the vectors of the two voltages must be equal in direction and magnitude.

VELOCITY OF PROPAGATION. Since a wave is a periodic disturbance in both space and time, the speed with which the wave may be considered to be travelling will be a function of the wave-length (a space quantity) and the frequency (a time quantity), and in general it may be stated that:

$$v = \gamma n,$$

where v is the velocity of advance,
γ is the wave-length
and n the frequency.

Newton deduced the fact that the velocity of a compression wave may be determined from a knowledge of the elasticity and density of the medium through which the wave is passing. He established the relation as:

$$v = \sqrt{\frac{\text{Modulus of elasticity}}{\text{Density}}}$$

In the case of gases and liquids the bulk modulus is employed, whilst for sound waves travelling along a narrow rod or wire Young's modulus of elasticity is adopted.

In the case of a dielectric the formula becomes

$v = \sqrt{\frac{\mu}{k}}$ where k is the dielectric constant and μ the permeability of the medium respectively

For electrical waves propagated through wires, a factor depending on the frequency must be introduced due to the skin effect (*q.v.*). *See* Electro-Magnetic Theory of Light; Frequency; Wave, *etc.*

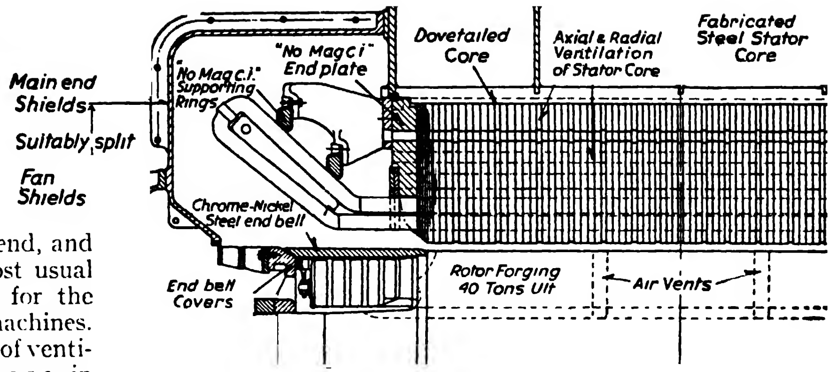
"V" END CONNEXIONS. In a bar-wound armature, *i.e.* one in which bars of rectangular section are employed instead of wires as armature conductors, the connexions from one coil to the next in series with it form a wide V and are therefore termed "V" end connexions. As solid copper strip except of favourable size gives trouble in winding, wires are usually preferred for medium-sized armatures. *See* A mature; End Connexions; Former-Wound Coil; Winding, *etc.*

VENTILATING FAN. *See* Fan.

VENTILATION (of Electrical Apparatus and Machines). In all types of electrical apparatus the losses, both electrical and mechanical, are converted into heat, and, in order to prevent the insulation being damaged by excessive temperature, this heat must be carried away as fast as it is produced. In most cases, this is done by allowing the heat to be carried away by air. It is only in recent years, however, that much thought on scientific lines has been given to the methods by which the heat can most satisfactorily be transferred from the machine to the air. Previously it had been left much to chance whether a machine would operate with a satisfactory temperature rise, but now this is almost a regular item in the course of design. The factors which must be taken into consideration when designing a ventilating system are both numerous and diverse, and can only be indicated in a general way.

The quantity of air which must be supplied to a piece of electrical apparatus depends mainly on four factors: (*a*) The rate at which the heat is generated; (*b*) the temperature of the cold air; (*c*) the permissible maximum temperature of the machine; and (*d*) to some extent on the design of the apparatus itself. For machines, roughly about 100 cubic feet of air per minute are required for each kW lost, but in a machine with a well-designed ventilating system the quantity may be considerably lower.

Systems of Ventilation for Machines. In small machines, the greater part of the heat is carried away by the air surrounding the carcass by means of convection currents. The heat is carried from the interior parts of the machine by conduction and radiation, although a certain amount of directional flow of the air may be produced by the rotating parts. Practice is generally tending towards the use of forced ventilation, even for fractional horse-power machines, not only because of reducing the size of the machine for a given rating, but because it enables machines to be produced with a much more consistent standard of performance. Air is drawn or driven through the machine by means of a fan fixed to the rotating



VENTILATION Fig. 1. Sectional elevation of alternator showing axial and radial ventilation of stator core.

part at one end, and this is the most usual method, even for the largest machines. The problems of ventilation increase in number with the size of machine, however, and a few of these are given by way of illustration.

The conductors in which heat is produced are embedded in slots, as a rule, and are covered with material which is a good heat insulator. The only way they can be cooled, therefore, is by passing the heat into the iron core which is in contact with the cooling air, and by conduction to the end connexions.

Quite a large proportion of the loss occurs in the iron itself, so that this heat must be carried away before that from the conductors can be. It is usual, therefore, to build up iron cores in lengths of about two or three inches, and then to leave gaps by means of spacers to allow the air to have access to the iron. Other advantages in providing these "ventilating ducts," as they are called, are that the cool air is allowed to come into contact with a greater area of surface, and that the heat does not have to pass through large masses of material before being transferred to the air.

As the cores are built up in an axial direction, the ventilating ducts left by the spacers are radial, and, in order to allow the air to get into these ducts, the stampings of the rotor must be built on a spider. In larger sized machines it is often necessary to provide axial holes through the stampings as well, so that the air may have a still greater contact surface. The terms used to denote the different types of ventilation so far described are "radial," "axial," and "mixed" flow. For the different methods of leading the air into and out of motors (and generators) reference should be made to the article on Motors, page 852, "Rating and Types of Enclosures."

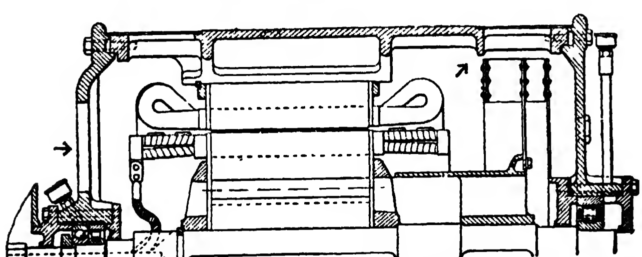


Fig. 2. Open type induction motor with direction of air currents indicated.

Special provision has to be made for the ventilation of the field coils on large machines. The heat from the inside of the coil is carried away to the frame by conduction, while the outside is in contact with the air circulating in the machine. To cool the interior of the coils, they are wound in sections, either concentrically or radially, thus reducing the thickness of section between the two surfaces. *See further under* Rotor, page 1052.)

Turbo-Alternators. In high-speed turbo-alternators, the ventilation requires special attention, as the long length of core introduces special problems. The rotors are usually made from forgings, so that continuous radial ducts are impracticable while even if possible the cooling of the conductors would not be adequate. Narrow slots are therefore made under the main slots for the cooling air while radial holes drilled from the surface give the air access to the core and so out to the stator.

For very long cores it is necessary to provide a fan at each end to drive the air towards the middle, as otherwise the air would be heated before it got to the far end. The tendency nowadays is to ventilate on the " multiple inlet " system. For this, the alternator frame is divided into compartments, alternate ones being connected to " inlet " and " exhaust," so that by this means the machine is divided into a number of short sections, while a large area is provided for the air to flow, thus reducing fan losses and keeping a more uniform temperature in the machine.

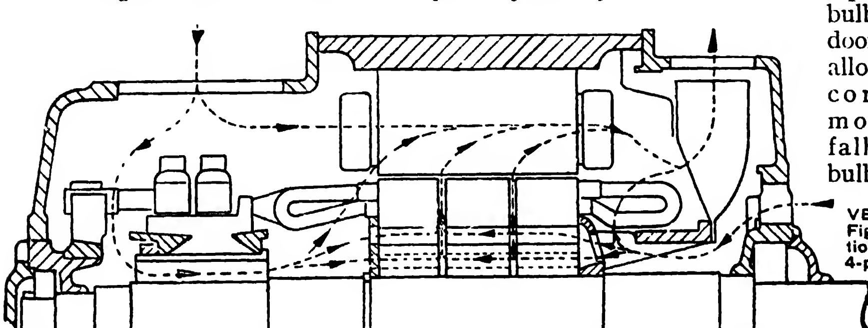
Large Turbo - Alternator Systems. Several different systems have been developed which involve the cleaning and cooling of the air before it is passed into the alternator, but most have one or another disadvantage. What is possibly the best method is described under Cooling of Alternators, page 43. In some cases separate fans are provided for driving the cooling air, but while these are somewhat more efficient than the built-in type, the latter are cheaper and have no complicating control gear.

Transformers. Small transformers of several hundred volt-ampère rating are usually made with the windings and core exposed to the air, and cooling takes place mainly by convection. Where the transformer is immersed in oil, the heat is carried from the winding by the oil to the tank, and from there is dissipated by convection and radiation. In some cases it is necessary to provide a corrugated tank to increase the cooling surface, this method being cheaper than fitting radiator tubes.

Several systems of cooling transformers of the largest size have been developed, but the tendency is now to rely on ordinary air cooling. To obtain the necessary surface area, a number of large corrugated " radiators " are fitted, these being specially designed to facilitate transport and cleaning. Although given the name " radiators," the bulk of the heat is carried away by contact and the setting up of air currents. This method is now being used on some of the largest units made, in some cases with forced blast cooling by means of fans. This system is also used in conjunction with ordinary cooling-tube transformers and some water-cooled transformers. (*See further under* Transformer.)

Other Apparatus. Heavy rating switches and fuses should be provided with adequate ventilation, especially the latter, as variations in the air temperature produce quite large variations in the fusing current. Mercury vapour, oxide, and thermionic rectifiers must all be placed so that an adequate circulation of air can be obtained, additional ventilation often being provided by means of a fan. In metal-clad mercury rectifiers, the anodes are usually provided with radiating fins to give additional cooling surface. Cable ducts must be built so that the air can sweep through to keep them clear of explosive gases. In some cases this may necessitate the use of a fan.

When high-power gas-filled lamps, projection lamps or flood-lighting units are used in enclosed fittings, adequate ventilation must be provided, the two main points are: Firstly, where the fitting is suspended by a tube carrying the cables, the hot air must not be allowed to rise up the tube, as this would perish the rubber insulation. Secondly, the ventilating holes must not permit jets of cold air to impinge on the bulb, or in outdoor fittings, allow rain or condensed moisture to fall on the bulb.



VENTILATION. Fig. 3. Ventilation circuits in a 4-pole machine.

British Thomson-Houston Co., Ltd.

Effects of Surroundings on Ventilation. When installing electrical machinery, care should be taken that the hot air from the exhaust end of the machine does not get deflected back to the intake end, or that the hot air from other machines is not drawn in at the intake. This means that the room in which machines are installed should have ample height or else have special provisions for keeping the air at a reasonable temperature.

Whether a machine is mounted on a steel, bedplate or directly on a concrete bed will make an appreciable difference to its temperature, and hence to the rate at which cooling air must be supplied. This is because the heat is conducted from the machine to the metal bedplate, which forms a large additional cooling surface. Where special ventilating arrangements have to be made, the manufacturers will usually specify them. *See* Alternator; Fan; Motor; Stator; Temperature Rise.

VIBRATING REED INSTRUMENT. *See* Vibrator.

VIBRATION GALVANOMETER. A sensitive suspended movement galvanometer which is used for the detection of minute alternating currents. The vibration galvanometer is used in A.C. potentiometer and bridge measurements, in which the method of testing is the adjustment of the circuit till the current in the galvanometer branch becomes zero. A vibration galvanometer is usually of the moving-coil type, and the natural period of vibration of the moving system is adjusted to be equal to the frequency of the A.C. circuit on which it is used. When this condition obtains, the presence of an alternating current in the moving coil will be indicated by vibration of the movement, whereby the spot of light on the scale screen will open out into an elongated band. Absence of current in the instrument is indicated by the spot of light being circular. The efficacy of a vibration galvanometer depends entirely upon its being mechanically tuned to the supply frequency, and, if the damping of the movement is small, the sensitivity of indication will fall off rapidly as the natural frequency of the movement becomes different from that of the supply. The sensitivity of the instrument also depends upon the damping, and a vibration galvanometer which is damped, either internally or by external shunting, will have its sensitivity less affected by differences in the mechanical and electrical frequencies than one whose damping is small. It therefore follows that if a vibration galvanometer is to be used in conditions of maximum sensitivity, the frequency of the testing supply must be maintained in exact correspondence with that of the instrument. If slight frequency variations are unavoidable, it is better to sacrifice sensitivity, by using the instrument shunted, as the extra damping so set up will render the galvanometer less liable to changes of sensitivity due to frequency variations.

VIBRATOR. A term somewhat loosely applied to a number of devices. The most common of these is the operating mechanism or vibrating armature of an electric bell (*q.v.*), particularly for telephones.

The term is also applied to the tuned reed used in some selective protective devices for transmission lines or transformers. These operate when a small A.C. current flows in a relay circuit. A current of fundamental frequency (50 cycles) only flows when there is a fault in the circuit. But higher harmonics (*see* Sine Curve) may flow when there is no fault. These must not cause operations, so the relay has to be rendered sensitive to the fundamental only. This is achieved with the help of a vibrating reed tuned to the fundamental frequency.

The relay only operates when this reed, called a "vibrator," is in motion.

Devices for producing high-frequency electric currents in wireless work are also sometimes called vibrators. Some of them generate voice-frequency currents, usually at about 800 cycles, some of them higher frequencies for heterodyning.

The term is also applied to certain rectifiers in which a vibrating reed reverses the current every half-cycle.

VIBRATORY PHASE ADVANCER. Also known as the Kapp phase advancer, a device for improving the power factor of slip-ring type induction motors.

Except that the armature is longer and of smaller diameter it is like that of any D.C. machine. There is one such phase advancer for each phase and they are

connected in the rotor circuit of the induction motor. The current through the phase advancer is, therefore, the same as the current in the rotor. This is an A.C. current of low frequency, because the freqeuncy is proportional to the slip of the motor. It is only one of a low number of cycles a second.

If each phase advancer V were supplied with D.C. it would keep rotating in one direction. But as the current reverses with slip frequency the direction of rotation of the armature also reverses with the same frequency. While the current is in one direction the armature of the phase advancer is steadily gathering speed. When the current changes to the opposite direction this armature cannot reverse suddenly. It slows down gradually and only reverses after a time. The slip current in the induction motor follows a sine curve (*q.v.*). It can be shown that the armature of the phase advancer stops and reverses nearly at the moment when the peak value of this sine curve has been reached, and that the armature has got up to its maximum speed when the sine curve passes through zero.

The result is that the armature acts like a motor while it is gathering speed, and it acts like a generator during the next quarter cycle while it is slowing down. At one quarter cycle it stores energy like a flywheel. At the next it gives this energy back. Consequently the induction motor is receiving current at times from its phase advancer and not only from the line. It can be shown that these supplies are just those needed to cause the current taken by the motor to be drawn from the line earlier than without the phase advancer.

V.I.R. CABLE. Vulcanized india rubber is one of the four dielectrics in general use for insulating electric cables, the other three dielectrics being vulcanized bitumen, varnished cambric, and impregnated paper. India rubber, dealt with in detail under the heading Rubber, is only superseded by impregnated paper for power cables. Its use in V.I.R. cable is also considered under the heading Cable.

The advantage of the V.I.R. cable lies in its great flexibility, the facility with which joints can be made and the low cost of installation, as fully explained under Conduit and Conduit Systems, and in particular under Wiring and Wiring Systems.

For ordinary house wiring certain standard thicknesses for the dielectric of V.I.R. cables have been adopted, and the quality of the dielectric varies according to the grade of cable required.

Standard thicknesses are ·034 inch for 1/·044 inch cable; ·036 inch for 3/·029 inch and 1/·064 inch cable; ·038 inch on 3/·036 inch; ·039 on 7/·029; and ·041 on 7/·036. The grades are: 2,500 megohm per mile highest quality, 600 meg. lowest non-association. The difference lies in the greater percentage of rubber added when mixing, giving high insulation resistance.

A form of flexible introduced by the G.E.C. for domestic electrical appliances known as "Domestaflex" eliminates the kinking difficulty. It consists of tinned copper-wire conductors, each insulated with two layers of V.I.R. in 600 megohm grade. The two insulated cores are laid up with whipcord inserts, filled with vulcanized rubber and braided with glazed cotton in a bi-colour combination overall, the external braid adhering tightly to the rubber filling. The whipcord inserts provide a separate means of attachment of the flexible to the plug (or other connecting device) and prevent any strain on the conductors themselves, either in normal use or if an appliance should be left hanging by the flexible. The close adhesion of the braid to the rubber filling prevents the cotton fraying with constant wear. Other forms of cotton-braided V.I.R. designed to avoid kinking and fraying are also made by Edison Swan, Henley's and other cable makers.

VIRTUAL AMPERES AND VOLTS. Readings of alternating current values based on the root mean square of the average values of their electro-motive forces. *See* Root Mean Square.

VOLT. The unit of electro-motive force. The practical unit of E.M.F. or potential difference is the International volt. It is defined as being that electro-motive force which, when steadily applied to a conductor having a resistance of one International ohm, creates in it a current of one International ampère. The potential

difference between two points on a conductor may be measured in terms of the work done in conveying a unit quantity of electricity from one point to the other. In general $E=W/Q$, where E is the potential difference in volts, W the work done in joules, and Q the quantity of electricity measured in coulombs. *See* Ampère; Circuit; Current; Electro-Motive Force; Kilovolt; Ohm; Resistance; Units.

VOLTAGE. Term applied to electromotive force or potential difference expressed in volts. Various specific applications of the term are discussed under their own headings throughout this work, and are listed and defined below:

ACTIVE VOLTAGE. The alternating voltage component which is in phase with the current in A.C. work.

DIAMETRICAL VOLTAGE. The voltage between opposite lines in a six-phase system.

IMPRESSED VOLTAGE. The E.M.F. applied to a part of a circuit in which there is a back E.M.F. opposing current flow.

LINE VOLTAGE. The voltage between two mains in a D.C. or single-phase system, or between phases in a polyphase system.

PEAK VOLTAGE. The maximum or crest value of an alternating voltage.

PRIMARY VOLTAGE. The input voltage at the primary terminals of a transformer.

STAR VOLTAGE. The voltage between any line and the neutral point of a star-connected system.

SYMMETRICAL VOLTAGE. Is said to exist when the instantaneous sum of the voltages in the various phases of a polyphase system equals zero.

VOLTAGE COEFFICIENT. Under the heading Electro-Motive Force (p. 549) the formula is given

$$e=\frac{p\phi nZ}{a\times 10^8}\text{ volts}$$

where p is the number of pairs of poles, ϕ is the flux per pole, n the number of revolutions per second, and a the number of parallel circuits through the armature, whilst Z is the total number of conductors on the armature surface. The ratio $\frac{p}{a\times 10^8}$ may be replaced by a constant K known as the voltage coefficient and the formula thus becomes

$$e=K\phi nZ\text{ volts}$$

where K depends on the nature of the armature winding and is constant for any one type of machine.

VOLTAGE CONTROL. Where the speed of motors is continually being changed over wide limits, or the speed has to be kept low for long periods, the use of variable field control alone will not produce
ance in the armature circuit is un-
the required range of speed, while resist-
economical. The latter method is also objectionable in that a change in load produces a change in speed. To obtain the necessary range of speeds a variable voltage is applied to the motor, the variation in voltage being obtained in a number of different ways, depending on the supply system in use.

In self-contained systems (*e.g.* Diesel-electric locomotive) the voltage is varied by a resistance in the generator field, and the generator is direct connected to the series driving motor, so that at starting or on slow running there is no need for resistance, in series with the armature. Where a three-wire D.C. system of distribution is used a range of low speeds can be obtained by connecting the armature of the motor between one outer and the middle wire of the system, the field being left connected between the two outers and varied to vary the speed.

If a wider range is required a special balancer (*q.v.*) set can be installed giving a four or a five-wire system with different voltages between any pair, so that, by connecting the armature across different lines, different speed ranges are obtained.

On trams, motor-coach trains and electric locomotives where more than one motor is used, economical running is obtained by connecting the motors in series at starting and for slow speeds, so that only half the voltage is applied to each. Where four motors are used on one driving unit, slow speeds are obtained by having all four in series, medium speeds by two in series, the double pair thus formed being connected in parallel, while for the highest speeds all are connected in parallel.

The only type of A.C. machine to which variable voltage speed control can be

applied is the commutator motor. The variable voltage may be obtained by a tapped transformer, either auto- or double-wound, or by means of an induction regulator. The tapped transformer method is much used in A.C. traction (*q.v.*), as distribution is usually effected at a much higher voltage than it is possible to operate the motors on, so that a transformer is essential, and the cost is only increased by that of the necessary tappings, while the control arrangements are relatively simple.

See Speed Control; Ward-Leonard System.

VOLTAGE DROP. When current flows in a conductor, some electrical pressure must be utilized in overcoming the resistance which the conductor offers to the flow of current. By Ohm's law, the pressure necessary to produce a given flow is proportional to the product of resistance and the current, and if these quantities are measured in ohms and ampères respectively, their product gives the required potential difference in volts. A similar statement is true for alternating currents provided impedance is used in place of resistance.

This voltage drop in a conductor when a current is flowing represents a loss of energy in the conductor in the form of heat. It is seen, therefore, that whenever current is carried from the source of supply to the point of utilization by cable or other means, there is a definite loss of energy in the cable itself. Usually the current rating of a cable is based on the heating effect produced by this lost energy, in that its temperature must be kept low to avoid damaging the insulation. In many cases, however, it is the voltage drop itself which limits the loading, as supply authorities must keep within a specified margin of their nominal voltage at the consumer's end.

Another consideration is that if the voltage drop became a large fraction of the total voltage, the transmission of the energy would become uneconomical, and it is a question of adjusting matters between the capital cost of the cable and the cost of the energy lost in it. From the consumer's point of view, the voltage drop lowers the voltage at his terminals, and this considerably reduces the efficiency of his lighting, and lowers the output obtainable from motors and heaters.

Transmission and Distribution. Where transmission of energy over long distances is carried out by either overhead line or underground cable, the following table of values will show how the voltage drop varies with the voltage of supply. For ease in comparison, it is assumed that the conductors would operate at a current density of 1,000 ampères per square inch, and that the power supplied is 1,000 kW.

Voltage	Current	Area of conductor	Resist. per mile	Volt drop per mile	Volt drop %
100	10,000	10 sq ins	·004 ohm	40	40
10,000	100	·1 ,,	·4 ,,	40	0·4
100,000	10	·01 ,,	4·0 ,,	40	0·04

The necessity for using high voltage to transmit large powers over long distances is at once obvious by inspection of these values.

Voltage Drop in Wiring Systems. In most cases buildings are wired in accordance with the I.E.E. ratings for cables at—any rate, so far as the current-carrying capacity is concerned. When a large building is being wired, however, it may be necessary to have the distribution box situated at some distance from the point of utilization, and in this case the voltage drop in the cables may have to be taken into account. A series of values are shown below, from the I.E.E. wiring table for rubber-insulated cables.

VOLTAGE DROP IN HOUSE WIRING

Size of wire	Cross-sectional area	Maximum current	Total length of circuit for 1 volt drop
1/·044″	0·0015	5	36 ft.
3/·036″	0·003	10	35 ,,
7/·029″	0·0045	15	34 ,,
7/·064″	0·0225	46	55 ,,
19/·064″	0·060	83	80 ,,
37/·064″	0·120	130	94 ,,

These values are modified if cables are bunched in conduits and not open.

"Total length of circuit" is length of "lead" and "return," so that 36 ft. for a 1-volt drop represents 18 ft. between two points. The reason that the length of cable to produce this drop increases with the size of the cable is that the smallest wire is worked at a current density of about

4,000 amps./sq. in., whilst the largest given is only 920 amps./sq. in.

Traction Systems. When an earthed return is provided on a traction system, *i.e.* return through track rails, the voltage drop between any two points on the earthed rails must not exceed 7 volts. The main object in limiting this drop is to avoid currents actually flowing in the earth itself, as these produce electrolytic corrosion on lead and iron pipes, and on lead cable sheaths.

Compensating for Voltage Drop. In D.C. systems the usual practice is to use a compound-wound generator, or, for traction purposes, a booster. On A.C. systems, the usual practice is to provide a tapped transformer or an induction regulator, the voltage being raised either manually or automatically as the current increases. *See* Booster; Compound Generator; Direct-Current Calculations; I.R. Drop; Line Drop; Losses; Resistance Drop.

VOLTAGE REGULATOR. A device for controlling the magnitude and, in some cases, the phase of the voltage of an A.C. circuit at a given point in a distribution network.

The term is also applied to the field regulators (*q.v.*) of A.C. and D.C. generators and to the tap-changing gear of transformers (*q.v.*). Such devices are not strictly voltage regulators because they can only regulate voltage when operating in conjunction with another piece of apparatus such as an alternator or a transformer.

Voltage regulators are usually applied to three-phase lines, but it is desirable first to consider the single-phase type. In its simplest form it consists of an iron-cored magnetic circuit on which there are two windings as in a transformer. The primary winding is connected across the mains and the secondary winding is connected in series with one of the conductors as shown in Fig. 1. The ratio of the turns is so chosen that the secondary voltage is a given fraction of the primary. If the ratio is 10 to 1 the voltage of the system will be increased by 10 per cent. by the action of the voltage regulator.

Types of Regulators. There are three methods of operating:

1. THE SWITCH-TYPE VOLTAGE REGULATOR. Provided with tap-changing gear which varies the ratio of the turns of the two windings by adjusting the number of turns in circuit by means of switchgear.

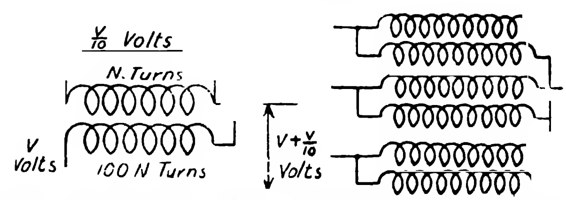
2. THE MAGNETO VOLTAGE REGULATOR. Has two fixed windings with a constant number of turns. The transformation ratio is altered by moving the iron core of the magnetic circuit so as to vary the magnetic interlinkage between the coils.

3. THE INDUCTION VOLTAGE REGULATOR. Has movable windings, and the transformation ratio is varied by moving the positions of the windings relative to each other. This type is described in detail under the heading Induction Regulator.

When voltage regulators are applied to a three-phase system, each phase is connected in series with a secondary winding as shown in Fig. 2. The primary windings are usually connected between one phase and neutral as shown. This limits the phase of the regulation to the phase of the system voltage. If regulation in another direction is required the primary winding can be connected across any of the three pairs of phases or from any phase to neutral. For complete control of magnitude and direction of the regulator voltage the primary windings can be split into two parts each supplied with a different phase of voltage and each variable in magnitude.

The three-phase induction regulator is wound like an induction motor, one of the windings being movable. One regulator by itself adds voltage of constant magnitude but of variable direction to each phase. Two are therefore used in conjunction with each other to give any required resultant regulation.

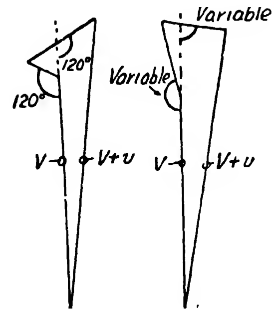
The magneto type does not lend itself so well for phase swinging and is chiefly used on single-phase circuits. Fig. 3 shows the vector diagrams of the switch



VOLTAGE REGULATOR. Fig. 1. Connexions of primary and secondary windings. Fig. 2. Secondary connexions for 3-phase system.

type and induction type for one phase of a three-phase regulator.

Scope of Voltage Regulators. Voltage regulators are chiefly used for controlling the sharing of load between different lines. Normally the current distributes itself over a network in such a way that the voltage drop between any two parts of the network is the same over all routes. This may cause the longer routes between two points to fail to carry their fair share of the load, and voltage regulators are used to force the current through them. On most systems the lay-out is such that the normal distribution of current is satisfactory and voltage regulators are only used as a last resource. They are more expensive than transformers of the same size, because both high and low voltage windings and their connexions have to be insulated for the full voltage of the line to earth.



VOLTAGE REGULATOR Fig. 3. (a) Regulation by addition of unequal voltages in fixed direction. (b) Regulation by addition of equal voltages in variable direction

A typical instance of the usefulness of voltage regulators is in the parallel operation of cables and feeders containing transformers. Such a system is shown in Fig. 4. The cables have high resistance and little reactance, and the transformers have high reactance and little resistance. The current will divide between the two paths so that the voltage drop in each is equal. This may lead to the cables being very much overloaded on account of the high reactance of the transformers choking the current in circuit with them. Also, the phase of the currents in the two paths will be nearly at right angles, and they will therefore be of no assistance to each other. If an attempt is made to correct this by varying the transformer ratio by means of tap-changing gear, a heavy wattless current will circulate and no alteration will be made to the sharing of the power current. In such a case, a voltage regulator, with complete phase-control, will enable the system to be operated satisfactorily. Such cases rarely occur in practice, because systems are so laid out as to avoid them.

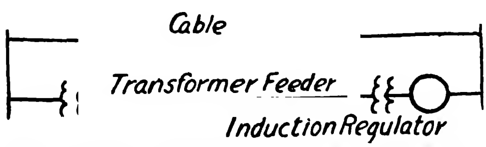


Fig. 4. Parallel operation of cables and feeders containing transformers.

The type of voltage regulator which accomplishes its purpose without additional plant in the main circuit is very common, and is essential for the operation of all large interconnected systems. The voltage is regulated either at the point of generation or at transforming stations.

At generating stations the voltage is regulated by means of field regulators (*q.v.*), the best known of which is the Tirrell Regulator (*q.v.*). Field regulators are usually automatic in operation. They control the field of the alternators, causing the required voltage to be generated at all loads. They are usually adjusted so that a rise in load gives a higher voltage to make up for the increased drop in the feeders through which power is delivered to the consumers. Regulators of this type are called compensated voltage regulators. (Their application to battery charging dynamos is discussed under that heading.) Used with

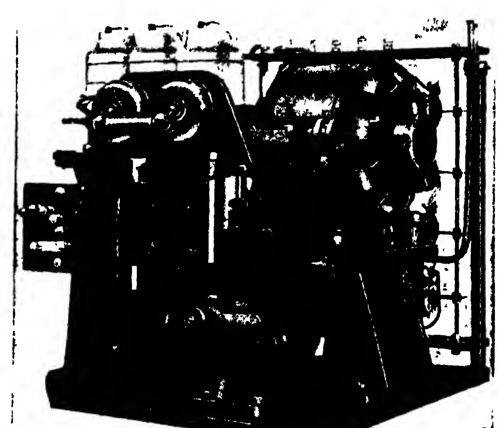
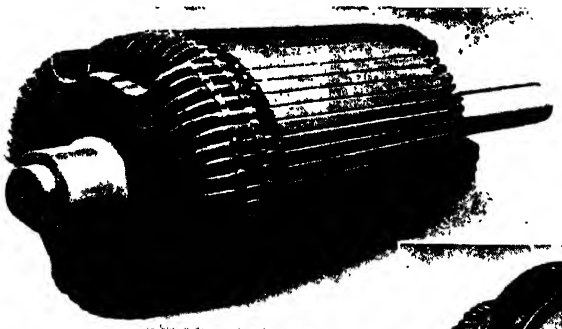
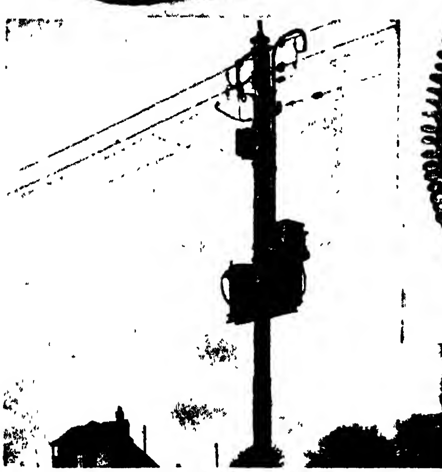


Fig. 5. Operating motor, brake and reduction gear for a voltage regulator set
English Electric Co., Ltd.



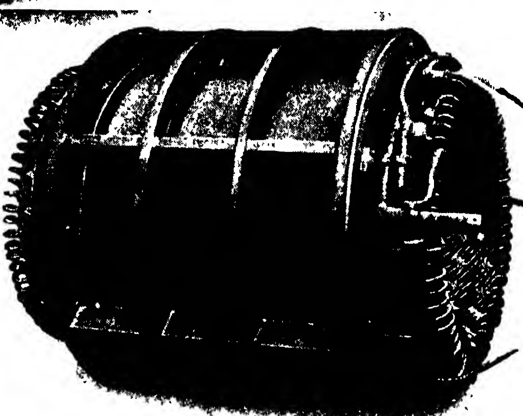


VOLTAGE REGULATOR. Fig. 6. 3·5-kVA pole-type induction regulator.
English Electric Co., Ltd.

alternators they cause them to have the same voltage characteristic as a compound-wound direct current generator (*q.v.*). When a number of alternators are operated in parallel and connected to the same bus-bars, special measures have to be taken to ensure that the voltage regulation is carried out in such a way that the wattless load is shared evenly by the machines. *See* Parallel Running of Alternators.

Brown-Boveri Regulator. Most automatic voltage regulators operate on the same system as the Tirrell regulator, where the whole of the regulator resistance is cut in and out at short intervals of less than one second. There is another type manufactured by Messrs. Brown-Boveri in very common use. This device inserts or removes resistance from the exciter field by specially designed sector-shaped contacts, which roll over the contact studs of the field rheostat. This avoids friction and enables a very rapid response to be obtained. The regulator operates to over-correct all changes in voltage in the manner of the Tirrell regulator. The regulator is quick in response, and is particularly easy to maintain in good running order.

Thury Regulator. For special applications, such as the regulation



Figs. 7 (above, left) and 8. Rotor and stator of 3-phase induction regulator.
English Electric Co., Ltd

of electric furnaces, the Thury type regulator is used. It consists of a variable rheostat driven by a motor which is constantly running. With steady voltage the motor runs free. If the voltage rises the motor is put into gear so as to notch in more resistance. If the voltage falls the gear notches out resistance. Special devices are added to prevent hunting. The Thury regulator is not generally encountered at central stations, because it does not compare well with other regulators in sensitivity, but its simplicity and ruggedness make it very suitable for industrial use. *See* Induction Regulator.

VOLTAGE TRANSFORMER. *See* Potential Transformer.

VOLTAMETER. A simple piece of apparatus devised for measuring current by the amount of a substance electrolytically deposited in a given time. The substance may be silver, copper, iodine, or a gas contained in an eudiometer tube.

The voltameter method of current measurement is indirect, and affords no indication of the magnitude of the current whilst it is flowing. Also it gives no indication as to whether the current

changed in value whilst electrolysis was in progress. The chemical effect is, therefore, of limited use, except for standardizing purposes, and for other purposes is generally replaced by some application of the magnetic effect (*see* Meters). For all cases where the utmost accuracy is not required, however, and where a special instrument is not available for comparison, the voltammeter affords the most reliable means for absolute calibration of ammeters.

VOLT-AMPÈRES AND THREE-PHASE POWER FACTOR. A three-phase circuit can be regarded as a combination of three single-phase circuits with a suppressed common return, and if the three-phase circuit is balanced, the power factor and volt-ampères are evidently identical with the common power factor and the total volt-ampères in the three identically loaded single-phase circuits. When the three-phase circuit is unbalanced the meaning to be assigned to the volt-ampères and power factor in the circuit is not so evident. A possible meaning for the volt-ampères in an unbalanced three-phase circuit is the sum of the volt-ampères in the three component single-phase circuits. Similarly, three-phase power factor might be defined as the ratio of the three-phase power to the total volt-ampères.

It is found more convenient in practice to define three-phase volt-ampères as the square root of the sum of the squares of the total watts and the total reactive VA in the circuit. This quantity is known as the total equivalent volt-ampères, and it is less than the arithmetical sum of the volt-ampères, unless the circuit is exactly balanced. This is due to the fact that, in an unbalanced circuit, the power factors of the component single-phase circuits are not equal. Similarly three-phase power factor is defined as the ratio of the watts to the total equivalent volt-ampères, or, alternatively, as the cosine of the angle whose tangent is the ratio of the total reactive VA to the total watts, these two definitions being actually identical.

The advantage of these definitions of volt-ampères and power factor is that they correspond to the values actually given by the use of watt-hour and reactive meters for volt-ampère measurement, and to the indications of power factor meters for power factor determinations. It should, however, be noted that, if the power factor of a three-phase circuit be considered as the cosine of an angle, this angle does not correspond to any actual phase angle in the circuit, unless this circuit be accurately balanced. *See* Kilovolt Ampère; Power Factor; Wattless Current.

VOLTMETER. An instrument for the measurement of the potential difference in volts between any two points in an electrical circuit. Excepting in the electrostatic type, all commercial voltmeters are essentially ammeters in that they measure the current in a constant resistance, which current, according to Ohm's law, is proportional to the applied voltage. The actual measuring portion of a voltmeter is therefore usually a milliammeter, and this movement is connected in series with a resistance. By adjustment of the value of the series resistance the range of a voltmeter can be varied between wide limits.

The current taken by a voltmeter when giving its full-scale deflection depends upon the sensitivity of the instrument. Increase of sensitivity can, however, only be obtained by increasing the actual voltage drop across the instrument movement. A voltmeter which takes a very small current will, therefore, require a greater fraction of the total applied voltage on its movement than one which is relatively insensitive. As the movement of a voltmeter has a copper circuit, while the series resistance is made of an alloy with a negligible temperature coefficient, increased sensitivity will tend to increase the overall temperature coefficient of resistance of the voltmeter circuit, so that the accuracy will be more affected by temperature variation. The minimum current for an instrument of given range is evidently fixed by the VA required to deflect the pointer of the movement from the 3rd to the full-scale position, against the control torque of the spring.

The various types of voltmeters in commercial use will be considered briefly below, but, as the underlying principle of these types is the same as those of the corresponding types of ammeters, these principles will not be discussed, as they are explained under the heading Ammeter.

Moving-Coil Voltmeters. These instruments are invariably used for all commercial D.C. circuits save those of very

high voltage. The standard current for the instrument for full-scale deflection is 15 mA for indicating voltmeters. For graphic recording instruments in which more power is required in the movement, the current allowed may be higher. All commercial instruments of this class are of First Grade accuracy, while Sub-standard accuracy can be given with portable testing instruments of robust design.

Moving-Iron Voltmeters. These instruments are now practically standard for commercial A.C. voltage measurements, and they can be obtained of First Grade accuracy in either the switchboard or portable patterns. Portable testing instruments of Sub-standard accuracy are now available.

Dynamometer Voltmeters. These instruments are described under the heading Dynamometers. They are the most accurate type for A.C. measurements, and can be used as transfer instruments whereby the determination of alternating voltages is made ultimately in terms of the standard cell. High-grade dynamometer voltmeters should be efficiently shielded, and used with care.

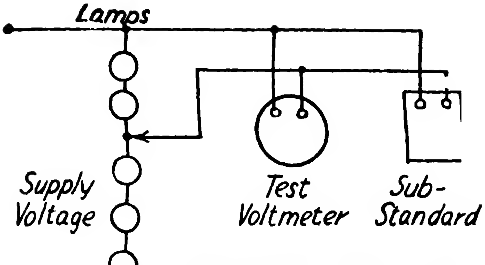
Hot-Wire Voltmeters. This was one of the first types of A.C. voltmeter to be brought into commercial use, the early Cardew pattern employing a wire which was housed in a long tubular extension to the case containing the pointer and dial. Although the objections to hot-wire instruments do not apply so seriously to voltmeters as to ammeters, the perfection of the more accurate and robust moving-iron type has rendered the hot-wire voltmeter practically obsolete in this country.

Thermo-couple Voltmeters. The characteristics, advantages and disadvantages of this type of instrument are similar to those of the thermo-couple Ammeter (*q.v.*) described elsewhere (*see* Ammeter). The principal application of this type is as a sensitive instrument for the measurement of alternating pressures of the order of millivolts. Care must be taken in the use of portable instruments of this type, as the overload capacity is relatively small, and the thermo-couple may be burnt out by the application of a voltage as little as 50 per cent. over that corresponding to the full-scale deflection.

Induction Voltmeters. Induction voltmeters depend for their operation on precisely the same principles as induction ammeters, and their use is now practically confined to switchboard measurements where an extended 300-degree scale is considered requisite. Induction voltmeters are tending to be superseded by the cheaper and simpler instruments of the moving-iron type.

Rectifier Type Voltmeters. The rectifier voltmeter consists of a moving-coil milliammeter and a rectifier network for double-wave rectification connected in series with a resistance to the voltage to be measured (*see* Rectifier Ammeter, page 55). Due to the fact that the resistance of the rectifiers is not constant, but increases as the current through them decreases, the scale of a rectifier voltmeter is only uniform through its entire range if the value of the series resistance is large as compared with that of the rectifiers. Rectifier instruments are largely used for the measurement of alternating voltages where an evenly divided scale is desirable. For the measurement of medium voltages they can be designed to take as small a current as 5 mA. Due to the variable resistance of the rectifier units this type of voltmeter is not inherently suitable for use as a millivoltmeter, as practically the whole of the voltage available will have to be absorbed in the rectifiers themselves, so that the instrument would have an uneven scale.

When it is not necessary to keep the current consumption of the instrument very low, small alternating voltages can be measured by a rectifier instrument connected to the secondary side of a step-up voltage transformer whose primary is energized by the voltage to be determined. In an instrument of this pattern giving full-scale deflection with 50 mV, the current in the primary of the step-up transformer is 0·5 ampère. Transformer operated rectifier millivoltmeters are used for measuring voltage drops on conductors carrying heavy alternating currents, where the relatively high current taken by the instrument is immaterial and where an evenly divided scale is specially advantageous. For the relations between the readings of a rectifier voltmeter on A.C. and D.C. the paragraph on Rectifier Ammeters (page 55) should be consulted.



VOLTMETER. Test circuit for checking a voltmeter.

Electrostatic Voltmeter. This is the only type of voltmeter which does not depend upon Ohm's law and which measures potential differences direct. The electrostatic voltmeter is described under that heading. Direct reading electrostatic voltmeters can be obtained with ranges from 20 to 150 volts up to voltages as high as 50,000. As an electrostatic voltmeter takes no current on D.C. and an almost inappreciable current on A.C., the range of this type of instrument cannot be extended by series resistances. Extension of range can, however, be obtained by joining the instrument in parallel with one of a series of condensers connected to the voltage to be measured. Electrostatic voltmeters must be efficiently shielded (*see* Shielding).

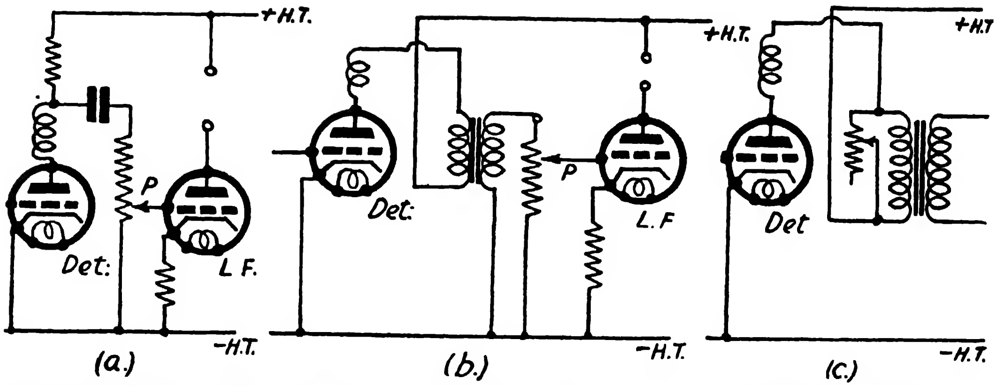
Testing. Commercial grade voltmeters are tested by a comparison of the reading of the instrument under test with that of a sub-standard instrument connected in parallel with it. Sub-standard A.C. voltmeters are tested by comparison with a high-grade D.C. instrument or by a potentiometer, the mean of two readings with the D.C. voltage reversed being taken on the test instrument. For the testing of a commercial grade voltmeter throughout its range against a sub.standard, the arrangement shown above is very easily made up. Here a number of lamps, corresponding to the number of test points required, are connected in series to the source of supply. The drop across each lamp will be approximately the same, if these lamps are of equal rating, and, connecting the two instruments in shunt to various numbers of lamps, the readings can be checked at several points of the scale. *See* Ammeter ; Instruments ; Test.

VOLTMETER PLUGS. For locations where it is undesirable to have a voltmeter permanently connected in circuit, a jack is sometimes provided into which a voltmeter may be plugged for purposes of measurement. Such plugs are extensively used in telephony, and were formerly employed to some extent in power work. Modern designers prefer instruments to be permanently incorporated on the control panel, affording visual indication at a glance of the voltage conditions on the circuit. They are still used for synchronizing voltmeters, however, which are not permanently in circuit. *See* Jack.

VOLUME CONTROL. There are many available methods of controlling the output volume from the loud speaker of a radio receiver and in practice the choice depends entirely on the type of receiver.

Before considering representative methods the necessary conditions to be fulfilled will be examined briefly. By means of the volume control it must be possible to adjust the output from the loud speaker to any desired level, whatever the signal strength may be at the aerial, within the usual limits. For the control to be perfectly satisfactory it must not in any way interfere with the general operating characteristics of the receiver. For instance, it must not affect the tuning or selectivity of the high-frequency circuits, nor the efficiency of the detector ; and, most important of all, it must not introduce distortion.

The volume control may be either in the L.F. circuits, after the detector, or in the H.F. circuits, and each method has its advantages and disadvantages, according to circumstances. For instance, the detector operates most efficiently when fully loaded and the best system of volume control is that which does not reduce the loading of the detector excessively when the volume is reduced. On the other hand, if the detector is overloaded a volume control must be included in the H.F. circuits to reduce the input to the detector. Clearly, then, the ideal system is to have two controls, one in the L.F. and another in the H.F. circuits. But for ease of operation a single-control knob is essential, and in many modern receivers the H.F. and L.F. controls are both incorporated, but are actuated simultaneously by the same knob. The more important methods are considered overleaf.



VOLUME CONTROL. Fig. 1. Methods of post-detector volume control ; (*a*) is perfectly satisfactory, but when transformer coupling is employed, (*c*) is usually more satisfactory than (*b*).

Post-Detector Controls. The most generally satisfactory method of post-detector control is to vary the input to the first L.F. stage by means of a potentiometer. The L.F. output voltage from the detector is applied across the ends of the potentiometer resistance and any desired fraction of this voltage is tapped off and applied to the grid of the next valve. Circuit arrangements for effecting this method of control are shown at (*a*) and (*b*) in Fig. 1, where resistance-capacity and transformer coupling respectively are employed. At (*a*) the potentiometer resistance P acts in the dual capacity of volume control and grid leak, and there are no objections. There is, however, an objection to the system shown at (*b*) where the slider resistance shunts the secondary winding of the transformer, especially when this is of high step-up ratio, the effect being to change the frequency response. A rather better method is to connect a variable resistance across the primary as at (*c*), where it sometimes introduces a desired tone correction at low volumes, where it attentuates middle frequencies to a greater extent than the upper and lower ones (*see* Tone Control and Correction).

Pre-Detector Volume Controls. As the signal strengths of the different transmissions to which a receiver is successively tuned are vastly different, some method of control before the detector stage is essential whether post-detector volume control is provided or not. Pre-detector control can be divided into two categories: (i) those systems in which the degree of radio-frequency amplification is varied, and (ii) those in which the signal voltage input from aerial to receiver is changed.

The variable-*mu* type of H.F. valve possesses the great advantage, as its name implies, of a variable amplification factor, the degree of H.F. amplification being dependent on the grid-bias voltage. It gives maximum amplification with about 1 volt negative grid bias, the amplification falling off gradually to zero as the

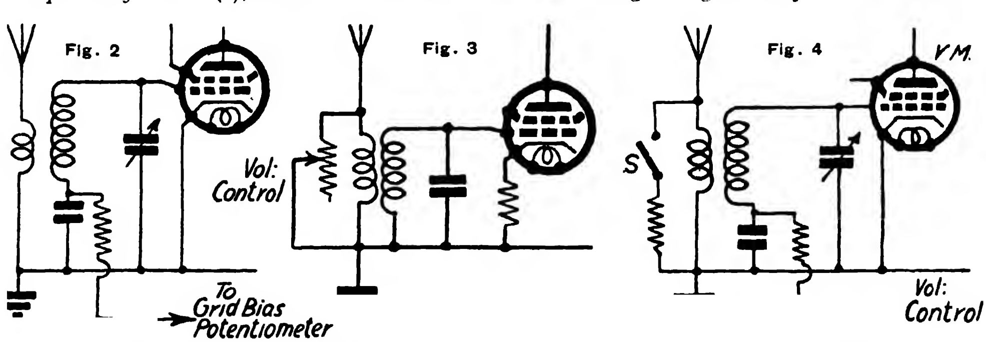


Fig. 2. The variable-*mu* H.F. valve gives almost ideal volume control by operating on the negative grid bias. Fig. 3. Volume control by shunting the aerial circuit. Fig. 4. To cope with very powerful local signals a "local-distance" switch S may be used to shunt the aerial by a suitable resistance.

bias is increased to -30 or 40 volts. As practically all modern receivers incorporate variable-*mu* valves in the H.F. stages (and intermediate stages also in a superheterodyne), this effect is universally employed for effecting pre-detector volume control, the variable grid bias being applied by means of a potentiometer. The principle is illustrated in Fig. 2, the potentiometer itself not being shown as it is usually connected in some other part of the circuit carrying a steady D.C. The system does not in any way affect the tuning conditions.

The second system referred to usually consists of shunting the aerial input circuit by a variable resistance as in Fig. 3 and will be found in many older receivers employing H.F. valves not of the variable-*mu* class. Although it is quite effective as a volume control it has the objection of affecting the tuning to some extent, a serious matter when band-pass filters and ganged circuits are used.

Local Distance Switch. In many instances, where variable-*mu* valves are used, the maximum available bias voltage is not sufficient to reduce the signals from a powerful local station to a sufficiently low level, and a " local distance " switch is provided to shunt a fixed resistance across the aerial circuit as in Fig. 4. The slight upsetting of the tuning is of no consequence, as interference with a powerful local station is not very likely. The closing of the local-distance switch does not put the normal volume control out of action, so the full range of volumes is still available.

It should be pointed out that reaction should not be used for adjusting volume unless very weak signals are being received. Increase of reaction not only raises the volume but increases the selectivity also, and usually results in loss of quality due to high-note attenuation. The reaction control should, therefore, be used only for increasing the selectivity in the event of interference or when receiving very weak signals. *See* Automatic Volume Control; Tone Correction.

VOLUME RESISTIVITY. Alternative name for specific resistance (*q.v.*) used to differentiate between mass resistivity (*q.v.*) and the resistance per unit length of unit area of cross-section of material.

"V" TYPE COMMUTATOR. The commonest form of commutator construction in which the segments are made with dovetailed projections which fit into the end clamping rings and are thus held securely in position. *See* Commutator.

W Abbreviation for watt (*q.v.*), the unit of electric power. Also symbol used for work or electrical energy.

WALL PLUG. An appliance for connecting portable and domestic electrical apparatus to a source of supply consisting of a wall socket, to which attachment may be made by means of suitable projecting pins. The following extracts from the I.E.E. regulations for the wiring of buildings are complementary to the B.S.I. specifications given under the heading Plugs:

SOCKET-OUTLETS AND PLUGS 1329 (A). A socket-outlet and plug shall not be used to carry a current greater than that for which they are rated.

(B). Every socket-outlet and plug shall conform in all respects to the appropriate British Standard Specification and shall also be so designed and constructed as to prevent a current-carrying pin of the plug from making contact with a current-carrying contact-tube of the socket-outlet while any pin of the plug is exposed.

(C). A plug containing a cut-out shall be non-reversible and shall be so arranged and connected that the cut-out will control an outer or phase conductor, or the non-earthed conductor of the circuit.

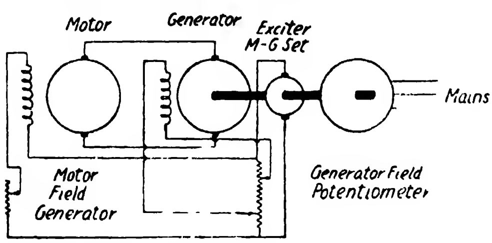
(D) Weatherproof socket-outlets and plugs shall be of specially robust construction and be provided with efficient means to maintain the socket-outlet weatherproof when the plug is removed therefrom. Where a loose cover is employed for this purpose, it shall be anchored to the socket-outlet by means of a chain. When the plug is inserted in its socket-outlet the combined fitting and interlocking switch, if any shall also be weatherproof.

WARD-LEONARD CONTROL SYSTEM. A special form of variable voltage speed control. It is adopted for drives which require: (*a*) a constant speed irrespective of the torque up to somewhat greater than full-load value; (*b*) a very gradual acceleration and deceleration; and (*c*) a range of speeds from crawling to full speed in either direction. The system is much used on large rotary printing presses, paper-making and rubber calendering machines and furnace and mine hoists, in all of which the above factors

are important, while a modified form, known as the Ward-Leonard-Ilgner system, is extensively used on rolling mills.

The variable voltage is obtained from a motor generator set, the generator field being supplied from a constant voltage exciter mounted on the same shaft. The generator field is supplied from the exciter through a potentiometer connected so that the field current can be continuously varied from a maximum in one direction to maximum in the reverse direction, as shown in the diagram. From this it is also seen that the motor field is supplied from the exciter through a resistance which enables the maximum speed to be varied.

The great drawback of the system is its high initial cost, as three machines of the same output are required, and its low efficiency, but it is the only system which



WARD-LEONARD CONTROL SYSTEM. Potentiometer control enables field current of generator to be varied from maximum in one direction to maximum in reverse.

will operate under the conditions required in the applications already detailed. It can be seen that the control gear necessary is simple, as no switches are required between generator and driving motor, the two being solidly connected.

The Ilgner modified system consists essentially of a Ward-Leonard set with a flywheel mounted on the shaft between the generator and its driving motor. The function of the flywheel is to avoid large variations in the load from being reflected as large current rushes in the mains as the load comes on suddenly, as it does in a steel-rolling mill. The object of this system is not so much to maintain constant speed as to avoid these heavy current rushes as the bloom passes between the rollers of the mill, and to provide a quickly reversible drive. Peak outputs of about five times the rated output of the generator driving motor are obtained by this system. *See* Motor Generator; Speed Control.

WASHING MACHINE. The electric washing machine consists of some means of oscillating in a tank of hot soapy water the linen or clothing to be washed. The usual method of oscillation is by rack and pinion drive from an electric motor which turns a vertical shaft carrying a horizontal disc upon which are mounted three or four paddles which catch up the linen, move it round for the portion of a full turn in one direction, and then return it against the movement of water which has thereby been produced, thus driving the soapy water through the materials to be washed.

In addition to the actual process of washing it is usual to provide as part of the equipment a roller wringer, operated through a reversing gear by the motor.

In certain models an electric heater is provided at the bottom of the tank to maintain the hot water at a correct temperature during the process of washing. The whole equipment is usually built in the form of a movable piece of apparatus mounted on wheels or castors, having a flexible cord connexion for insertion in a convenient plug socket.

The power required to drive such a machine is extremely small, being of the order of $\frac{1}{4}$ h.p.

The term "washing machine" usually includes the equipment more commonly known as a wash-boiler. In this apparatus the principle is entirely different and less elaborate.

In this the tank or container has a conical-shaped funnel, which is placed with its wide end at the bottom of the tank and narrowing towards a vertical pipe which runs upwards towards the top of the tank. Above the mouth of this pipe a cap or deflector is fixed.

The cone with its cap is placed inside the boiler and the whole is filled with soapy water; the clothes to be washed are then placed in the water. Surface elements on the under-side of the bottom of the container heat up the water under the cone until a certain amount of steam is generated which forces up the hot water through the vertical pipe, where it is sprayed outwards by the deflector to the outer side of the cone, where it falls back through the clothes to be washed; this circulating movement is maintained so long as the wash-boiler is in use.

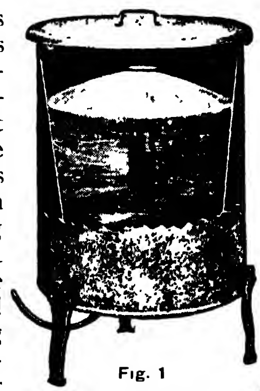


Fig. 1

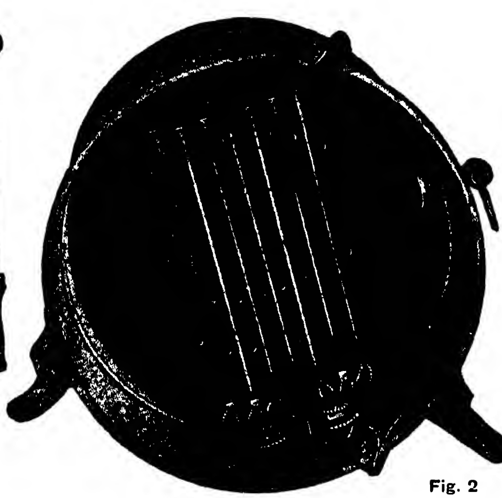


Fig. 2

WASHING MACHINE Fig. 1. "Ghost" view of G.E.C. wash boiler. Fig 2. Underneath view showing elements of "Santon" wash boiler.

The wash boiler is not so effective as the washing machine, nor is it so expensive. It cannot be used for delicate fabrics, since its process depends on the use of boiling water, which is not necessary in the case of the mechanical electric washing machine. The loading of a wash boiler is of the order of 3 kW.

WATCHES (Magnetized). The introduction of an ordinary watch into a strong magnetic field will seriously impair its timekeeping qualities. This is due to magnetization of the balance spring causing disturbing forces between its turns. In the older types of two-pole dynamos the stray fields were sufficiently strong to produce this effect on any watches in their vicinity.

A watch so damaged may be restored to its original state and completely demagnetized by introducing and gradually withdrawing it from a solenoid carrying an alternating current. Alternatively, demagnetization will result from spinning it whilst withdrawing from a strong magnetic field.

Non-magnetic alloys are employed as substitutes for steel wherever it may be used in the works of such watches. The composition of the alloys varies from 45–75 parts of palladium, 15–30 parts of copper, 20–25 parts of silver, together with small quantities of iron, steel, gold, nickel and platinum. These alloys do not oxidize in moist air, preserve their elasticity indefinitely, do not vary with change of temperature, and are unaffected by the proximity of magnetic fields.

Another non-magnetic alloy contains 30–40 parts of gold, 30–40 parts of palladium, 10–20 parts of copper, 0·1–5 parts of rhodium, 0·1–5 parts of manganese, and similar proportions of silver and platinum.

WATER HEATING. The heat equivalent of one unit of electricity is 3,412 B.Th.U. The quantity of heat required to raise a given quantity of water a specified number of degrees is equally definite, being the product of the weight of water in lb. multiplied by the rise in temperature in °F. It is thus a very simple matter to calculate the electricity consumption necessary to any specific water-heating problem. Further, if the time in which the heating is to be effected is known the calculations can be carried a stage further to determine the kW loading required. These simple facts are emphasized because patent electric water heaters are constantly being placed on the market for which impossible performance claims are made. The following formulae will enable any such claims to be rapidly checked; and they give the essential basic data for any water-heating problem.

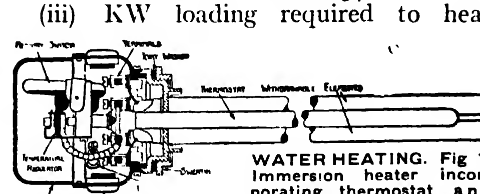
(i) Gallons of water that can be heated through a specified temperature in a stated time by a known kW loading:

$$\text{Gallons} = \frac{\text{kW} \times 341 \times \text{Hours}}{\text{Rise in } ^\circ\text{F}}.$$

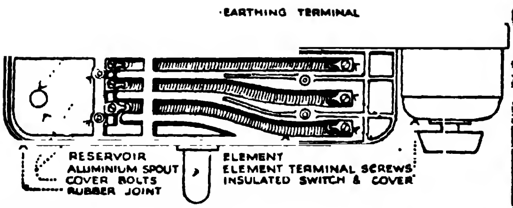
(ii) Time required with known kW loading to heat given quantity of water through specified temperature rise:

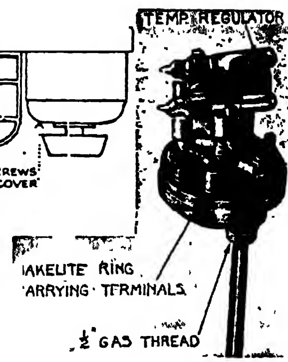
$$\text{Time in hours} = \frac{\text{Gallons} \times {}^\circ\text{F rise}}{\text{kW} \times 341}.$$

(iii) KW loading required to heat



WATER HEATING. Fig 1. Immersion heater incorporating thermostat and withdrawable elements, for horizontal fixing.
Santon, Ltd.





WATER HEATING. Fig 2. Electric geyser providing continuous flow of hot water. Fig. 3 (right). Temperature regulator for immersion heater shown in Fig. 1.

Santon, Ltd.

given quantity of water through stated temperature rise in fixed time:

$$\text{kW Loading} = \frac{\text{Gallons} \times {}^\circ\text{F rise}}{\text{Hours} \times 3411}.$$

The above assume 100 per cent. efficiency. Where the apparatus efficiency is known, or assumed, it can be applied (expressed as a decimal value, *i.e.* 85 per cent. = ·85), as a multiplier to the numerator in formula (i); and as multiplier to denominator in formulae (ii) and (iii).

Additional to the above it is useful to remember for quick approximation that 1 unit of electricity will boil 2 gallons of water; furnish 3 gallons of scalding water (about 160° F.) for washing up; or supply 6 gallons of water at bath temperature (105° F.).

Examination of the above formulæ will show that if it is required to heat large quantities of water quickly in a short time, high electrical loadings are necessary. Conversely, with low electrical loadings increased time for heating must be allowed. Hence are derived the two main classes of electric water heater. Geysers, in which the heating is done quickly as and when required, characterized by relatively high loadings; and thermal storage heaters (*q.v.*), in which the heating is done over long periods, characterized by low loadings.

In practice, for domestic use, geysers find little favour. With this type a loading of 20 to 24 kW would be required to give a bath in a reasonably short space of time. Geysers loaded 2 – 3 kW are satisfactory to supply a single isolated wash basin, for dental surgeon's requirements, and the like. But even in these applications a small thermal storage tank, 1½–2½ gallons loaded 500 watts, is probably to be preferred. For the vast majority of domestic requirements some form of thermal storage (*q.v.*) is normally employed—self-contained tanks up to 20 to 30 gallons capacity, loaded 100 watts per gallon, or immersion heater (*q.v.*) installation of 2 to 3 kW loading.

WATERTIGHT FITTINGS. When electric apparatus such as motors, switchgear and other fittings are placed in positions where they are liable, from time to time, to be flooded with water, they must be not merely enclosed, but enclosed in a watertight case. The driving of pumping machinery in some classes of mines is a case in point. A cast-iron casing is usually adopted, with packed joints tightened by glands for all cable entries, joint boxes, etc.

Smaller sizes of circuit breakers for outdoor situations are usually housed in small sheet-steel weatherproof kiosks, but in the larger sizes the gear is erected in the open and for this purpose vertical draw-out switchgear has undoubted advantages over the horizontal draw-out types. The circuit breakers are enclosed in cast-iron cases with grummet or gasket watertight joints between the covers, the body and the oil tanks. The domed covers throw off the rainwater and the cases are so shaped that moisture which might run down the outside of the breaker is prevented from creeping into the oil-tank. The tanks are hydraulically tested before leaving the manufacturer's works to a pressure of 50 lb. per square inch or more according to the breaker rating.

Similarly, disconnecting boxes of the pavement type are provided with lids of the diving-bell pattern, capable of resisting a six-foot head of water with a reasonable margin of safety.

Iron-clad fuse-boxes and outdoor switches for all exposed situations, such as exterior control of neon signs, etc., have machined faces and rubber packing between case and cover to render them watertight, whilst special bushes are employed for cable entry to such boxes.

Bulkhead lighting fittings, as extensively adopted on ship-board, in mining galleries and generally in exposed positions, are also provided with machine-faced joints and rubber or leather packing rings.

Watertight plugs and sockets, often of the flush pattern, are employed in docks and factories where sluicing down or flooding with water is a common occurrence. When not in use the socket, of lacquered brass or steel bronzed, is provided with a watertight screw-on cap.

See Motors; Switchgear.

WATT and WATT-HOUR (Wh). Unit of electrical power. Equivalent to work done at the rate of one joule per second. A kilowatt is a thousand watts, and 746 watts equal one horse-power. The commercial unit of electric work is the watt-hour. It is the work done in one hour by a current of one ampère flowing between two points of a conductor having a difference of potential of one volt. One watt-hour equals 3,600 joules = 2,654 foot-pounds. This unit is too small in practice usually, and the legal unit of electrical energy is the kilowatt-hour or Board of Trade (B.O.T.) unit, sometimes called the kelvin, equal to 1,000 watt-hours. *See* Joule; Kilowatt; Units.

WATT-HOUR METER. A registering meter which integrates power, or measures energy expended in an electric circuit. Watt-hour meters are in fundamental construction identical with wattmeters, excepting that, instead of the moving system being controlled by a spring, it is free to rotate continuously against the dynamic braking torque due to the movement of a disc in the field of a permanent magnet. A unique type of watt-hour meter which does not comply with this description is the Aron clock meter, described under that heading.

The basic principles of various types of watt-hour meters are described under Meter. It is there shown that these instruments can be classified as under:

Mercury Type Watt-hour Meters. Suitable only for D.C. circuits and accurate only over a limited voltage range.

Dynamometer Type Watt-hour Meters. Nominally suitable for both A.C. and D.C. circuits, but practically confined to a very limited use for D.C. work.

Aron Clock Meters. Nominally suitable for both D.C. and A.C. circuits, but practically used in D.C. circuits only. The Aron meter has a high inherent accuracy over the whole of its current and voltage ranges.

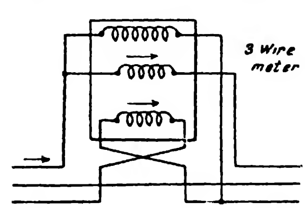
Induction Type Watt-hour Meters. Suitable only for A.C. circuits, and practically the only type of meter used for this work.

In this article are considered a few matters relating to watt-hour meters which are not dealt with elsewhere.

Three-Wire Meters. According to theoretical principles, two meters are required to measure the energy in any three-wire circuit, whether D.C., single-phase A.C. or three-phase. For D.C. and three-wire single-phase A.C. circuits, an approximate measurement of the total energy can be made by a single meter with two-current windings, each being connected in the "outer" conductors of the system, the voltage circuit of the meter being connected between these two conductors. The meter integrates the product of the average current in the outers and the maximum voltage, and is only accurate if both outer-to-neutral voltages are the same.

Aron meters can be arranged as three-wire instruments without modification, as they normally have two current coils. The error due to voltage unbalance can be eliminated by joining the common connexion of the pendulum coils to the neutral of the system.

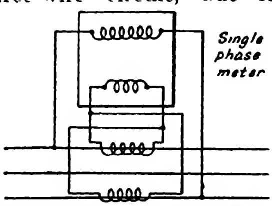
Balanced Load Three-Phase Meters. If a three-phase circuit carries a balanced load, so that all three-line circuits and all three-line voltages are respectively equal, the energy in this circuit can be measured by a single meter. One method of doing this is shown in Fig. 1, where a three-wire single-phase meter is used, each coil being connected in one of the lines of the system. An alternative method, using an ordinary single-phase meter with two current transformers, is shown in Fig. 2, and it is evident that



WATT-HOUR METER. Fig. 1 Connexions for a 3-wire single phase watt-hour meter on a balanced load.

the principle of the two methods is identical.

These methods appear to be the same in principle as that of the metering of a single-phase three-wire circuit, but it should be noted that, whereas single-phase three-wire meters are quite accurate with balanced voltages, however unequal the line currents may be, a single meter can only measure three-phase energy if the currents as well as voltages are accurately balanced, and considerable errors can occur with slight current unbalance. Single-phase meters are only used for approximate measurements in three-phase circuits, and are not legally recognized for the purpose of charging for the supply to a consumer.



WATT-HOUR METER. Fig. 2. Connexions for a single-phase meter with two current transformers on balanced load.

Phase Errors of Induction Watt-hour Meters. It is explained under the heading Meter that induction meters are fitted with a phase compensating device, so that the eddy currents induced in the disc by the voltage flux are in phase with the alternating field due to the current coils, when the circuit current and voltage are in phase. If this compensation is inexact, the effect on the meter performance will be the same as if the phase difference of the line current and voltage had been modified. Under-compensation will be the same as the supply voltage leading on its natural phase, so that the phase difference of current and voltage is increased with lagging power factors and the meter registers slow. The phase angle of an induction watt-hour meter is similar to that of a dynamometer wattmeter (*see* Wattmeter).

If an induction wattmeter is used with current and voltage transformers, the errors of these transformers will affect the accuracy of the meter. Ratio errors will affect the accuracy correspondingly, but the effect of instrument transformer phase errors, like that of inherent phase error of the meter, depends upon the power factor of the load measured. The phase error of a voltage transformer is constant at all loads, and can be allowed for by introducing a compensating phase error in the meter. Phase errors of current transformers are such as to cause the secondary current to lead the primary current, so that on lagging loads the apparent power factor on the meter is decreased, and the meter tends to register high. Phase errors of current transformers vary with the load, increasing as the load diminishes, and so cannot be completely compensated in the meter.

Testing Watt-hour Meters. Watt-hour meters are tested either by comparing the speeds at various loads with the theoretically correct speed corresponding to the indication of a sub-standard meter, or by energizing the voltage circuit of a special sub-standard watt-hour meter while the test meter rotor executes an exact number of revolutions. The sub-standard meter used in this test is equipped with a special pointer whereby small fractions of a revolution of its rotor can be accurately observed, and its accuracy over its entire range is checked independently by careful speed tests against a standard wattmeter.

The phase error of a wattmeter is best obtained by testing it with artificial power factors of 0·5 leading and lagging. The lag and lead corresponding to 0·5 power factor is 60 degrees, and as tan 60° is 1·73, and the effect of phase error is opposite on leading to lagging power factors, the difference in the errors given by the two tests will be $2 \times 1{\cdot}73$, or about 3·5 times sin α, where α is the angle of phase error.

The sine of 1 degree is 0·017, and the tangent of 45 degrees is unity. A phase angle error of 1 degree thus causes an error of 1·7 per cent. at a power factor of $\cos 45° = 0{\cdot}71$.

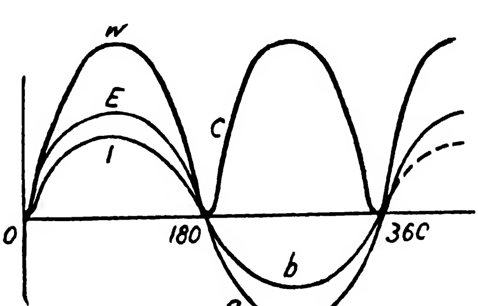
Three-phase watt-hour meters should, strictly speaking, be tested on a three-phase circuit, but results which are sufficiently accurate for practical purposes can be obtained by testing on a single-phase circuit, the voltage circuits being connected in parallel and the current circuits in series. *See* Instruments.

WATTLESS CURRENT. Confusion often arises in the minds of laymen and junior students of electrical matters when they

attempt a study of the energy and power quantities in A.C. circuits. This confusion is due to the unfortunate nomenclature, involving, in at least the case under consideration, an apparent contradiction in terms. In point of fact, there is no more reason for saying that a current is wattless than there is for saying that the E.M.F. driving it is wattless. Since the E.M.F. of supply is usually kept constant, the beginner is tempted to regard the power delivered as the property of the current only, whereas watts are the product of E.M.F. and current, and it is absurd to suppose that they are due to one more than to the other. Furthermore, it is absolutely impossible to have a current flowing in a circuit without the expenditure of some power.

At the same time, in A.C. work we do obtain, in some instances, a large current and high voltage supply, yet the actual power transmitted is so small as to be practically negligible. Thus, when a central station supplies a network of conductors to which the primary circuits of a number of unloaded transformers are connected, the angle of lag will be so great that the power transmitted is very small indeed. The angle of lag (as explained under that heading) represents the phase difference between the voltage and current quantities. The idea will perhaps be more clearly understood by reference to the curves in Figs. 1 and 2.

In Fig. 1 the current and E.M.F. curves are in phase. Both are positive throughout the same period of time and both negative throughout an identical period; hence the product is at all times positive and the average value of the power is



WATTLESS CURRENT. Fig. 1. Curve showing product of volts and amperes (i.e. power), with no phase difference.

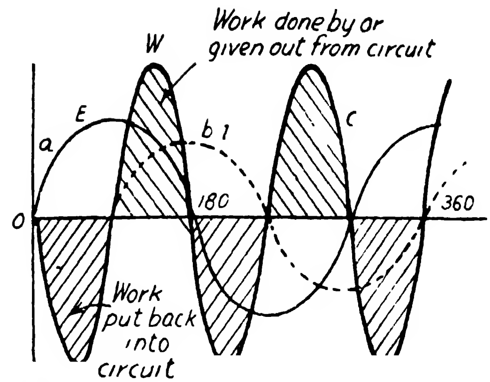


Fig. 2. Curve illustrating alternating functions of E.M.F. and current unproductive of actual power

represented by the area under the curve *c* divided by the length of the ordinate, and will obviously be of considerable size. In Fig. 2, however, an angle of lag equal to 90 degrees has been introduced, and it will be observed that the average value of the power has now become zero. In other words, as the angle of lag or lead approaches 90 degrees (*i.e.* with pure inductance or capacitance in circuit), so the average value of the power decreases until, as in Fig. 2, it becomes negligible. Yet the current and E.M.F. quantities are the same in both cases. It is the angle of lag which determines whether the power in the circuit shall be useful or idle.

To overcome the difficulty it was suggested that the current might be regarded as being made up of two components at right angles to one another, one of which —a small one—was in step with the E.M.F., and the other—considerably larger in size—90 degrees behind it. Of these two components, the small one was the "power current," and the one which lagged by 90 degrees was the "wattless current." The explanation is useful as a mathematical device but apt to be misleading as regards physical facts. The impression is conveyed that there are two currents flowing in the circuit, the power current and the idle current. This is, of course, not true—the analogy serves its purpose, but like all analogies must be kept within carefully defined limits.

The definition of wattless current, then, is that when a circuit is so inductive that the A.C. current lags practically 90°, or when the circuit has such a capacity

that the current leads practically 90° over the volts, the current is said to be a wattless current.

Considering a circuit containing an inductance only, to which an E.M.F. is applied whose instantaneous value e = E sin θ, the resulting current lags by 90°, and is therefore given by

$$\begin{aligned} i &= \mathrm{I} \sin (\theta - 90^\circ) \\ &= -\mathrm{I} \cos \theta \end{aligned}$$

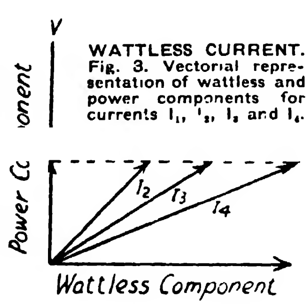
The instantaneous value of power

$$\begin{aligned} p &= -e\,i \text{ watts} \\ &= -\mathrm{EI} \sin \theta \cos \theta \\ &= -\frac{\mathrm{EI}}{2} \sin 2\theta \text{ watts} \end{aligned}$$

Average power

$$\begin{aligned} \mathrm{P} &= \frac{1}{2\pi}\int_0^{2\pi} e\,i\,\delta\theta \\ &= -\frac{\mathrm{EI}}{4\pi}\int_0^{2\pi} \sin 2\theta\,\delta\theta \\ &= \frac{\mathrm{EI}}{4\pi}\left[\frac{\cos 2\theta}{2}\right]_0^{2\pi} \\ &= 0 \end{aligned}$$

This proves mathematically that for a purely inductive circuit the average power is zero and similarly for a purely capacitative circuit. Nevertheless, current is still flowing in the circuit, as during a quarter cycle when the current is building up from zero to maximum, energy given to the circuit is stored up in the magnetic field, and during the next quarter cycle when the current is decreasing the stored energy is given back to the supply system, on a similar principle to the flywheel. Since no external work is done by this current, *i.e.* no watts produced in an external load, it is referred to as the idle or wattless component, and it represents a loss in energy to the supply system when such a current is required.



WATTLESS CURRENT. Fig. 3. Vectorial representation of wattless and power components for currents I_1, I_2, I_3 and I_4.

Reference to the diagram (Fig. 3) may tend to clarify the idea. Four machines of the same power output but of different inductance take four different values of current I_1, I_2, I_3 and I_4. Each of these currents represents the same power, since the power component is the same in each case, yet the fourth takes more than twice as much current as the first. Since connexion of a highly inductive circuit to the supply mains would result in lowering the power factor of the mains as a whole, with consequent increase in the wattless component of all consumers connected to the main, supply companies protect themselves by imposing penalties on such loads. *See* Power Factor; Reactive Current; Tariffs; Volt-ampères, *etc.*

WATTMETER. An instrument which indicates directly the power in an A.C. or a D.C. circuit. In an A.C. circuit, the power is defined as the average of the instantaneous products of ampères by volts, so that the torque on a wattmeter movement must be also proportional, at any time, to the product of the current in its windings by the voltage applied to it. Wattmeters are rarely used for commercial measurements in D.C. circuits, since the power in such circuits is, with constant voltage, proportional to the current, and ammeter indications are sufficient. In A.C. circuits the current is not, even with constant voltage, a measure of the power, so that switchboard-type wattmeters are largely used for the control of alternators and converting sets.

The wattmeter is the fundamental sub-standard instrument used in the checking of A.C. supply meters, and for this duty high accuracy is essential. Sub-standard wattmeters must be of such a type that they can be checked on direct current by comparing their readings with the product of the values of current and voltage given by a potentiometer. By the use of a sub-standard wattmeter in this way as a transfer instrument, A.C. measurements may be ultimately referred to the D.C. standard cell.

Wattmeters are conveniently discussed in a classification based on their underlying principles of operation.

Dynamometer Wattmeters. These are referred to under the heading Dynamometer (*see* page 399), and consist essentially of a pivoted moving coil, free to turn against the control of a spring in the field of a fixed coil. The moving coil carries a current proportional to the voltage of the circuit, and the current in the fixed coil is proportional to the circuit current. If the field due to the fixed coil, which is embraced by the moving coil, is

sensibly constant for all working positions of the movement, the scale of the instrument will be uniform. The voltage range of the instrument can be adjusted at will by variation of the value of the resistance in series with the moving coil. Two current ranges can usually be provided by connecting the two fixed coils in series or parallel, but shunting the fixed coils is not permissible if the instrument is to be used in A.C. circuits.

The dynamometer instrument is invariably used for high-grade testing and standardizing work. It will indicate on both D.C. and A.C. circuits and is thus suitable as a transfer instrument.

In order that a dynamometer wattmeter may give exactly the same reading in A.C. and D.C. circuits carrying identical amounts of power, certain important requirements must be satisfied. The torque on the movement of such an instrument is due to the interaction of the fixed field with the current in the moving coil. It is therefore essential that with a given voltage the current in the moving coil be the same whether this voltage be direct or alternating. If the moving-coil circuit be quite free from inductance and self-capacitance this condition will be satisfied.

Phase Errors. Suppose, however, that the moving coil is slightly inductive. The effect of the inductance will be first that the current in the circuit with a given voltage is slightly less with A.C. than with D.C. and, secondly, that the moving-coil current will lag in phase on the voltage producing it. With a very small inductance the first effect is not important, but the second effect is serious if the instrument is used on an A.C. circuit of low power factor. If the current in such a circuit lags on the voltage, the effect of inductance is the same as if the phase of the voltage were brought nearer to that of the current, and the instrument will read high. If the angular difference between the phase of the moving-coil current and that of the voltage be α, and the instrument be used in a circuit of power factor cos ϕ, the practical error will be very nearly sin α tan ϕ. Now, as ϕ approaches 90° tan ϕ becomes very large, so that even with a small value of α a large fractional error may occur if ϕ is nearly 90 degrees. The angle α, the tangent of which is equal to the ratio of reactance to resistance of the voltage circuit, is known as the phase error of the wattmeter.

A second source of phase error is that due to what is known as self-capacitance, and is due to a minute additional current which flows in the voltage circuit of a wattmeter used in an A.C. circuit due to capacitance between the different sections of the series resistance. This error causes the moving-coil current to lead in phase on the voltage and thus tends to correct the phase error due to inductance.

It will readily be understood that phase error tends to increase as the frequency increases, as both reactance and capacitance current which give rise to this error depend on frequency.

We have already referred to the fact that the current range of a dynamometer wattmeter cannot be modified by shunting, and it will easily be understood that the effect of a shunt to the moving coil would be to cause an error due to a possible difference in the phases of the currents in the shunt and the moving coil.

Phase errors in the current circuit can be caused by eddy currents set up in any metal in the field of the fixed coil. These currents can even be set up in the material of the coil itself. The effect of eddy currents is to reduce the field due to a given current and to cause the phase of this field to lag on that of the current. The eddy current effect is small in wattmeters for relatively low currents, if the use of metal formers is avoided. In heavy current wattmeters this phase error can be minimized by stranding the conductors forming the moving coil, but the inherent accuracy of such a wattmeter is less than one designed for small currents. For this reason, most precision measurements of A.C. power are made by 5-ampère wattmeters used in conjunction with high-grade variable-ratio current transformers. The effect of the errors of instrument transformers on the accuracy of power and energy measurements is referred to under the heading Watt-hour Meters.

The phase error of a sub-standard wattmeter can conveniently be measured by connecting the instrument in a test current in which the current and voltage

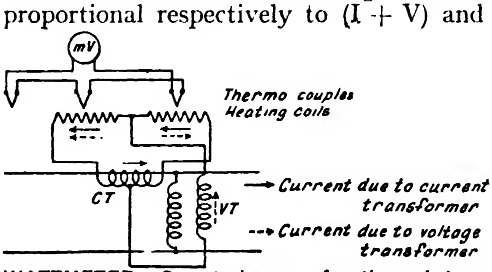
have values corresponding to the wattmeter ranges, and a phase difference of exactly 90 degrees. If the phase error is zero, the wattmeter reading is zero also. The ratio of the reading to the product of ampères by volts is very nearly equal to the sine of the phase error. In most modern high-grade 5-ampère wattmeters the phase error is inappreciable.

High-grade dynamometer wattmeters must be efficiently shielded from the effects of extraneous fields (*see* Shielding).

Induction Wattmeters. These are referred to under Induction Instruments (*see* pages 600 and 824), and the underlying principle is exactly the same as that of induction watt-hour meters. These instruments are suitable for A.C. circuits only and will not read with D.C. Induction wattmeters are limited in use to switchboard instruments, and phase errors, so important in precision measurements, are not so vital for switchboard measurements.

Electrostatic Wattmeters. These instruments are described under the heading Electrostatic Wattmeter, page 472. The extreme delicacy of such instruments limits their use to standardizing laboratories of the highest class.

Thermal Wattmeters. An interesting thermal type of wattmeter has been developed for the purpose of indicating the value of the power in an A.C. circuit at a considerable distance from the measuring position. The principle of this instrument will be made clear from a consideration of the annexed diagram. Two heating coils are energized from a current and a voltage transformer in such a way that one coil carries the sum and the other the difference of the secondary currents. These heating coils give rise to E.M.F. in two thermo-couple circuits which are connected in opposition. The instantaneous currents in the heating coils are proportional respectively to (I + V) and



WATTMETER. Circuit diagram for thermal type wattmeter.

(I – V) and the heating effects, upon which the thermo-electric effect depends, are proportional to the squares of these quantities. The resultant average D.C. voltage from the thermo-couple combination is thus proportional to $(I + V)^2 - (I - V)^2$ or to IV. The value of the power in the A.C. circuit can thus be indicated by a sensitive moving coil D.C. millivoltmeter located at a considerable distance from the heating coils and instrument transformers. The accuracy of this method of power measurement is not high, and its sole advantage is its suitability for remote indication.

Three-Phase Wattmeters. Wattmeters for indicating directly the power in a 3-phase circuit can be constructed by assembling two dynamometer or two induction movements so that they communicate torque to a common moving system. The principle of such instruments is the same as that of 3-phase meters (*q.v.*). The accuracy of 3-phase wattmeters is inherently inferior to that of the normal single-phase type. *See* Instruments; Kilovolt-Ampère-Hour Meter; Meters; Watt-hour Meter.

WAVE. Any disturbance which is periodic both in space and time is known as a wave. The speed-time relationship constitutes the wave form, and may be represented by the fundamental equation of wave motion, namely,

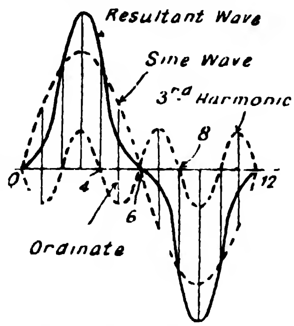
$$d^2y \qquad d^2y$$

In alternating current work with which the electrical engineer is chiefly concerned, the wave form of current usually takes the shape of a sine curve (*see* Harmonics). For particulars as to the form of wireless waves *see* Aerial, Heaviside Layer, *etc.* The waves employed in wireless range up to several thousand metres in length. *See* Radiation; Sine Curve; Wave Analysis; Wavelength.

WAVE ANALYSIS. A graphical record of the time variation of an alternating quantity, such as is given by an oscillograph, indicates the wave form of the alternation. Except in transient conditions, successive wave forms of alternating electrical quantities are the same. This identity of form is expressed by the statement that the alternations are periodic, and, according to a mathematical theorem of Fourier, any periodic wave

form can be resolved into harmonic components, the frequencies of which are integral multiples of the fundamental frequency.

This principle is illustrated in the accompanying diagram, which shows a fundamental harmonic or sine wave on which is superimposed a second wave of triple frequency. The resultant wave is said to be peaky. Had the third harmonic been reversed at the time the fundamental was zero, the resultant wave would have been dimpled and flat topped.



WAVE ANALYSIS. Fundamental harmonic with triple frequency harmonic superimposed (dotted curves) result in peaked wave (shown in full lines).

The wave forms of alternating voltages met with in practice are usually sine shaped, but non-sine shaped or distorted waves of current often occur, when a circuit of variable impedance is fed by a sine-shaped voltage. A familiar example of a distorted wave of current occurs when a transformer is on open secondary circuit. Due to magnetic saturation, the impedance of the transformer is much less for high than for low values of the voltage, with the result that the wave form of the exciting current is peaky, as shown in the figure. The wave forms of alternating electrical quantities are usually symmetrical about the zero axis. This denotes that the frequencies of the harmonics are all odd multiples of the fundamental frequency.

The analysis of a wave consists in the determination of the amplitudes and phases of the harmonics which are superposed upon the fundamental. The analysis can be carried out geometrically on an actual curve giving the wave form, or electrically without the wave form being actually obtained.

Harmonic Values. The geometrical method of wave analysis is too complicated to be dealt with completely, but the underlying principle can be partly understood from an examination of the figure. It will be seen that the whole curve is divided into 12 parts by equally spaced ordinates. This is the construction for the determination of the third harmonic, the half wave being divided into twice as many parts as are the order of the harmonic to be found.

If we consider a set of three ordinates, spaced four sections of the curve apart, it is easy to see that the algebraic sum of these ordinates for the fundamental harmonic is zero, but that for the third harmonic they are all equal. Adding up such a set of ordinates, we obtain three times the value of the third harmonic at one point on the time-axis. Adding similarly a second set of ordinates, displaced one section of the curve from the first, we obtain three times the value of the third harmonic for a phase 90 degrees displaced from the first. From the two values of the third harmonic so found, its amplitude and phase can be determined. The fifth harmonic is similarly found by dividing the curve into 20 parts. Having found the several harmonics, the magnitude and phase of the fundamental are determined as a residue. For details as to the complete analysis of alternating waves, textbooks of A.C. theory must be consulted.

The harmonics in the wave of an alternating current or voltage can be measured directly, by applying the voltage, or a voltage proportional to the current, to one circuit of a dynamometer, the other circuit of which is excited by sine-shaped voltages which are integral multiples of the nominal frequency of the wave under investigation. It is a fundamental principle of a dynamometer that no average torque is given unless the currents in its two circuits have the same frequency. If the testing voltage has the fundamental frequency, the reading of the dynamometer will correspond to the fundamental harmonic in the voltage tested. Exciting the dynamometer with a triple-frequency voltage, the response of the dynamometer is to the third harmonic only, and so on. In an instrument of this kind for wave analysis, means are provided for varying the phase of the testing voltage, and the amplitude of the harmonic is given by the maximum reading of the dynamometer as the phase of the test voltage is varied, while the phase of the harmonic with respect to the

fundamental is given by the phase of the testing voltage at which the dynamometer reading becomes zero.

WAVE FILTER. A device incorporated in wireless receivers to eliminate waves of undesirable frequencies, such as the upper side-band (*q.v.*). Modern, highly selective super-heterodyne sets incorporate a wave filter in practically every stage, consisting of a combination of capacity, inductance and resistance, having a much lower impedance to certain specified frequencies than others. The circuit is outlined in detail under the heading Filter (*q.v.*). Wave filters are also used extensively in telephone repeaters to suppress the disturbing harmonics resulting in a pure fundamental oscillation.

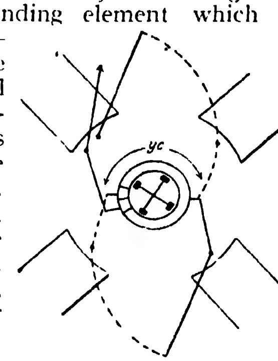
WAVE-LENGTH. The distance between corresponding phases of consecutive waves in a wave train, measured in the direction of propagation at any instant.

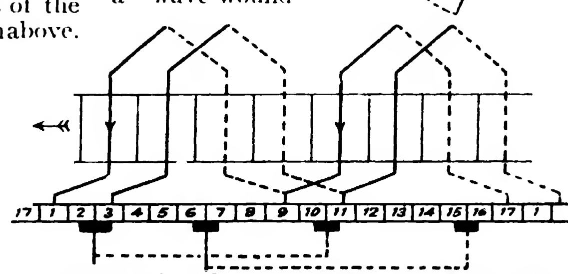
The wave-lengths and frequencies of the most important ether waves are given above. *See* Frequency; Kilocycle; Wave.

Ray	Frequency	Wave-length
Cosmic	above 3×10^{20} cycles	below 10^{-10} cm.
Gamma rays	,, 3×10^{19} ,,	,, 3×10^{-9} ,,
X-rays	,, 10^{16} ,,	,, 3×10^{-8} ,,
Ultra-violet	,, $7{\cdot}6 \times 10^{14}$,,	,, 4×10^{-5} ,,
Violet light	$6{\cdot}6 \times 10^{14}$,, (approx.)	4×10^{-5} ,, (approx.)
Blue light	$6{\cdot}6 \times 10^{14}$,, ,,	$4{\cdot}5 \times 10^{-5}$,, ,,
Green light	$6{\cdot}1 \times 10^{14}$,, ,,	$4{\cdot}9 \times 10^{-5}$,, ,,
Yellow light	$5{\cdot}1 \times 10^{14}$,, ,,	$5{\cdot}88 \times 10^{-5}$,, ,,
Orange light	$4{\cdot}6 \times 10^{14}$,, ,,	$6{\cdot}52 \times 10^{-5}$,, ,,
Orange red light	$3{\cdot}8 \times 10^{14}$,, ,,	$7{\cdot}89 \times 10^{-5}$,, ,,
Red light	$2{\cdot}7 \times 10^{14}$,, ,,	8×10^{-5} ,, ,,
Infra-red	above $3{\cdot}1 \times 10^{11}$,,	below 10^{-2}
Micro-radio	,, 3×10^{10} ,,	,, 1 cm
Electronic oscillations ..	,, 3×10^{8} ,,	,, 300 cms.
Ultra-short	,, 3×10^{7} ,,	,, 1,000 ,,
Short	,, 3×10^{6} ,,	,, 10^{4} ,,
Broadcasting and services	,, 3×10^{5} ,,	,, 10^{5} ,,
Medium	,, 10[illegible] ,,	,, 3×10^{5} cms
Long (commercial) ..	,, 5×10^{3} ,,	,, 60×10^{5} ,,
Radiations from low-frequency A C ...	,, 30 cycles	,, 10^{7} cms

WAVE WINDING. Also known as series armature winding. One of the two main forms of armature winding, in which winding elements lying under adjacent pole pairs are connected in series, and the series is connected to adjacent commutator bars. In a 4-pole machine there will be two winding elements in series, and in a machine with $2p$ poles there will be p elements in series between adjacent commutator segments. The principle will be understood by reference to the diagrams. In Fig. 1 the series connexion can be traced out through the armature.

There will be $2p$ neutral points opposite pole centres as shown in Fig. 2. Alternate neutral points are joined together by a single winding element which is practically neutral, and there is no potential difference between brushes at alternate neutral points. Theoretically, two brushes, one positive and one negative, should suffice for a wave-wound





WAVE WINDING Fig. 1 (above). Winding elements under adjacent pole pairs are connected in series. Fig. 2 (below). Connexion of coils to commutator segments.

machine; but in practice, except for smaller sizes, it is customary to divide the brushes up equally between all the neutral points, thereby reducing the risk of flash-over between segments. A comparison of the advantages of wave and lap windings respectively is given under the latter heading (*q.v.*).

WAX. Waxes are characterized by their high dielectric strength, surface resistivity, chemical inertness and waterproofing qualities, and the fact that they melt at comparatively low temperatures and re-solidify unchanged on cooling. In the electrical industry they are used either for their dielectric or waterproofing properties, or both. True waxes are of animal or vegetable origin—those of chief importance for electrical purposes are beeswax, carnauba wax, spermaceti and Chinese wax.

Beeswax melts at about 60° C–65° C, has a dielectric strength of about 250 volts/mil, and is used as an ingredient for certain types of insulating varnishes, and of certain compounds used for impregnating cotton and silk covered wires and cables. Carnauba wax is similarly employed, and is used in the preparation of certain types of flexible varnishes for the enamel covering of wires.

Mineral waxes, such as paraffin and montan wax and ozokerite, differ from true waxes in containing no oxygen, but have similar characteristics. Paraffin wax melts at temperatures from 45–80° C., has a permittivity ranging from 1·9–2·3 (depending on its composition) and a dielectric strength of about 300 volts/mil. It is used in the manufacture of certain types of electrical condensers and small batteries, and is sometimes used for impregnating the cotton covering of wires, and also for impregnating thin electrical papers for use as interlayer insulation on small coils.

Synthetic waxes, such as the "Seekay" manufactured by the I.C.I., are produced by the controlled chlorination of naphthalene. Unlike natural waxes, "Seekay" waxes are non-inflammable, and may be obtained with m.p.'s ranging from 68° C.–123° C. These have a permittivity of 5·4, a volume resistivity of 2×10^{13} ohms/cm³. *See* Insulation.

WEDGE CONTACTS. For currents above 600 amps., and in many lower rated oil circuit breakers, the plain knife blade in laminated spring contacts is replaced by the wedge-shaped contact construction. This consists of an inverted V blade with sides sloping at 15 degrees, built up from two flat copper strips bolted to a supporting casting. Alternatively, a flawless cast copper blade may be employed, filed and whorled to give a true surface, and then coated with fine grease or petroleum jelly.

Three-phase plunger switches usually have the three main wedge contacts carried on a horizontal insulated arm at right angles to the plunger rod. The three contacts are separated in the oil tank by elephant-hide partitions.

Self-alining split contact fingers convey current to the blade, a number of independent contacts being thus obtained. Each contact surface is cleaned every time the switch is operated, due to the rubbing action, whilst the pressure of the fingers tends to help the springs which trip the switch.

Replaceable copper sparking tips are often provided with wedge contacts to take the brunt of the sparking produced at make and break, being screwed on to each end of the wedged casting. Current densities up to 125 ampères per square inch and over may safely be dealt with by such contacts. *See* Circuit Breaker; Contacts; Knife Switch, *etc.*

WEHNELT CATHODE AND INTERRUPTER. An electrolytic interrupter acting on a somewhat different principle from those described under the heading Interrupter (*q.v.*). In this type a thin platinum wire forming one terminal is immersed to a greater or lesser degree through an aperture in a porcelain tube, the end of which is placed in a jar containing dilute sulphuric acid in the proportion of 1 oz. of acid to 5 oz. of water. The other electrode consists of a plate of stout lead sheet. A minimum electromotive force of 25 volts has to be used with this type of interrupter to break down the electrolyte, and a current of not less than five ampères.

The platinum is made the anode, and the lead the cathode. On closing the circuit, the density of the current is so great as to cause the formation of steam, and in addition electrolysis causes hydrogen and oxygen to appear, these gases

forming round the anode an insulating mantle which interrupts the current. If there is a sufficient amount of self-induction in the circuit a spark appears at the point of " break," that is the anode, igniting the gases. A small explosion ensues, which gives the acid access once more to the platinum point, and closes the circuit again. This process goes on with extraordinary rapidity and regularity.

The intensity of the discharge and the frequency of the interruptions can be adjusted between wide limits by varying the electro-motive force of the primary circuit, the exposed surface of the platinum point, and the amount of self-induction in circuit. The character of the spark discharge from a coil actuated by an electrolytic break differs from that of a hammer or mercury break in an extraordinary manner, probably owing to its extreme rapidity of action, and the use of a condenser shunted across the terminals of the break seems to be unnecessary. Great care is needed in experiments with these interrupters when substituting them for the mechanical or mercury types, or an excellent spark coil may be ruined in a few seconds.

WELDING BY ELECTRICITY: MODERN METHODS

By J. H. Paterson, D.Sc., F.I.C.

This specialist subject is here dealt with by a specialist, the article being in two sections, Fusion Welding and Pressure or Resistance Welding, the latter including butt, spot and seam welding. The recently introduced atomic hydrogen method is also described. The special form of welding employed in accumulator work is described under Lead Burning.

The oldest method of joining pieces of iron and steel consists in heating the abutting edges to a bright red heat and hammering till union is effected. Some of the iron is burnt to oxide or scale during this operation, and has a tendency to remain in the metal and thus cause a weak joint. This method of welding has always had unsatisfactory features, and until recent years it also suffered from the disadvantage of only being applicable to small articles.

With the advent of the manufacture of combustible gases such as coal gas, and later acetylene, it was found that very high local temperatures could be produced by mixing these gases with oxygen and burning them in special burners. This temperature was so high that iron and steel could easily be melted locally, and even boiled, so that by melting the abutting edges of two pieces of steel plate till they ran together, and then allowing the job to cool, a weld quite free from slag and other impurities could be obtained. Welds made by the oxy-acetylene method are called fusion welds, to distinguish them from the old smith's weld which is now called a percussion weld.

As all that is necessary to produce a fusion weld is a source of intense local heat, the heat generated in an electric arc was used at an early stage in the development of fusion welds. To-day electric welding is much the most commonly used method of joining iron and steel, as well as aluminium and aluminium alloys and a number of other non-ferrous metals.

Electric welding methods are conveniently divided into two main groups: (a) fusion welding methods; (b) pressure welding methods.

ELECTRIC FUSION WELDING

In this process the heat from an electric arc is used to melt the metal which is to be welded, and the variations of the process depend essentially on the kind of arc which is used. The three common methods are:

1. Carbon arc welding.
2. Metallic arc welding.
3. Atomic hydrogen welding.

Carbon Arc Welding. A carbon rod is held in a special clamp or holder, which the operator manipulates with one hand. This holder is connected to one pole of a 60-volt D.C. generator, and the work to be welded is connected to the other pole. Regulation of the current used is obtained by inserting a resistance in series with the arc in the welding circuit (Fig. 1). The voltage drop across

the arc is from 30–45 volts, and the current strength required, which varies with the length of the arc, may be from 100–600 amps. for welding steel castings, or from 30–300 amps. for welding steel plate. The process is largely used, in addition to welding up defective castings, for welding flanges to large diameter steel pipes.

Metallic Arc Welding. The principles are the same as those employed in carbon arc welding, but a metallic rod of similar composition to the metal to be welded is used in the place of the carbon.

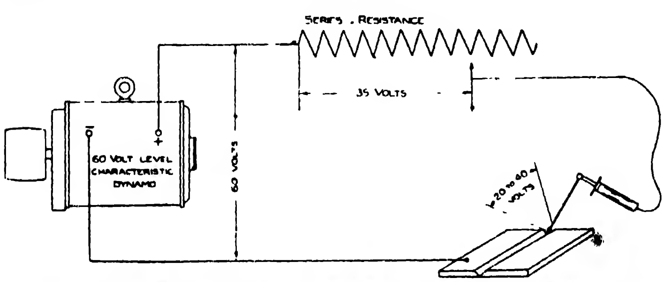
Under the heat of the arc the metallic rods melt at the same time as the work melts, and the liquid metal from these two sources, joining together, produces the weld. The process is much faster than the older carbon arc method, and the heat generated is very much less, so that it is now usually regarded as the most important method of welding metals, particularly iron and steel. The metallic arc rod which forms one pole of the arc is now always called the electrode, and these rods are usually covered with some material which will also melt in the heat of the arc, and perform the double function of fluxing out all the oxides from the melted metal, and also preventing the metal from becoming chilled by cooling too quickly, as it forms a kind of blanket over the top of the weld metal.

Electrodes vary very much in the method of manufacture, but they are all standard so far as size is concerned, being marketed in 18-inch lengths, of which one inch is left bare of coating so that the electrode holder may make proper electrical contact with the core wire. Different thicknesses of work call for different diameters of core wire, and these are always expressed in standard wire gauges. Various authorities have stated the exact mechanical properties which the deposited metal from an iron electrode must produce to meet their requirements, the average figures for mild steel welding electrodes being:

Tensile strength: 28–30 tons per sq. in.
Elongation on 8 ins.: 20 per cent.
Impact value (Izod): 40 ft. pounds.

The average current strength required for the different gauges of electrodes varies with the thickness of the material on which the welding is being done, but it lies within the following limits:

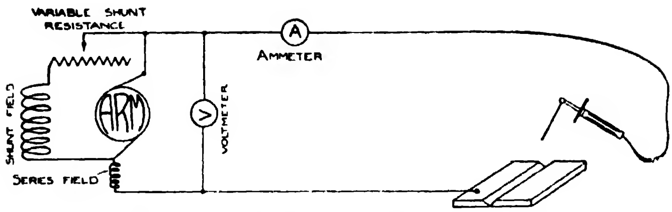
S.W.G.	Current Strength (Amps.)
4	180–260
6	140–200
8	125–160
10	90–120
12	65–95
14	40–65
16	20–35



WELDING. Fig. 1. Resistance in series with the arc affords regulation of the current.

Plant for Metallic Arc Welding (Single Operator). It is a phenomenon of the electric arc that it requires a much higher voltage to strike the arc than is needed to maintain it once it is struck. For easy starting a voltage of 60 with D.C., or 65/100, depending on the type of electrode, with A.C. plant which meets these requirements and at the same time gives smooth welding characteristics, is therefore necessary for good welding. When direct current is used, the arrangement shown in Fig. 1 for carbon arc welding gives satisfactory results except that the resistance (on a 60-volt circuit) will be required to absorb from 35–40 volts, and carry currents for ordinary welding operations up to about 250 amps. It is a common practice to place a special form of choking coil in series with the variable resistance in the welding circuit. If this coil has a sufficiently large iron core it helps very considerably to stabilize the circuit and makes welding easier for the operator.

Special D.C. Generator. The overall efficiency of above type of plant is obviously very low, rarely exceeding 30 per cent., and various forms of welding generator have been designed to do away with the



WELDING. Fig. 2. Shunt field provides striking voltage, and series field regulates working current.

external resistance. The generator most commonly used to-day is of the *drooping characteristic* type, which has an open circuit voltage of from 60 70, this voltage falling to the arc voltage immediately the arc is struck. A common method of construction is shown in Fig. 2. A shunt field taking its current either from the main dynamo or from a separate exciter provides the main field excitation, and is regulated by means of a small series resistance. A series field, wound in the opposite sense to the shunt field, is also provided. When there is no load on the dynamo, the shunt field provides the necessary striking voltage, but when welding commences the opposed series winding partially demagnetizes the field and the voltage falls by a predetermined amount to the welding voltage.

Regulation of the amount of current supplied by the dynamo is accomplished by the adjustment of the shunt-field resistance, and on standard machines gives a range of from 30 amps. to the maximum in about 5 amp. steps. The overall efficiency of this type of dynamo may be as high as 65 per cent. It should be noted that the drooping characteristic machine is essentially a single operator machine, because as soon as the operator has started, the voltage falls to the welding voltage and it would be impossible for a second operator to cut in.

A.C. Supply. When using A.C. for welding, the necessary plant is extremely simple. A step-down transformer is required to convert the main supply to the necessary welding voltage, which is usually a little higher than when D.C. is used. Most modern welding transformers have a tapped secondary enabling pressures of 60, 75 and 100 volts to be obtained. By this means the requirements of different makes of electrode, which vary somewhat, are fully met. Regulation of the current supply is obtained by means of a choking coil of the usual A.C. type. In some forms of this coil the regulation is accomplished by drawing the laminated core out of the coil either by hand or by a worm screw arrangement, while in other types the core is fixed, and the coil is tapped at appropriate intervals to give current strengths from the minimum to the maximum with 10 amp. intervals. In Fig. 3, which shows the usual arrangement of a transformer and choke unit, the choking coil is of the tapped type.

The welding arc can, of course, only be maintained on one phase of a polyphase supply, so that when single operator equipment is to be considered there is always an out-of-balance load on the phase supplying the welding current. The majority of transformer equipments which are sold for one welder have a single phase primary winding only, and are connected to one phase of the incoming supply. Some supply authorities prohibit this practice, however, and transformers are made with the primary Scott connected (*see* Scott Connexion) for the three-phase supply, the secondary being single-phase as usual. Fig. 3 already referred to shows the external connexions of such a type.

Power Factor Improvement. The power factor of a single phase A.C. circuit is obviously very poor. The usual open circuit voltage is 75, and this has to be choked down to 25 volts for ordinary welding, so that the best power factor obtainable will be something less than 33 per cent. or 0·33. Usually it is about 31·5 per cent., although this is sometimes improved on by lowering the open circuit voltage below 75.

There are two alternative methods of dealing with this problem, both of which,

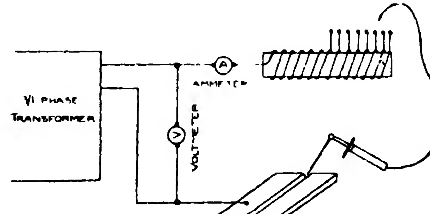


Fig. 3 Arrangement of transformer and tapped choke-control unit.

however, have drawbacks. In the first case a bank of condensers can be incorporated in the primary circuit, with sufficient capacity to bring cos θ back nearly to unity. This device is expensive and can lead to complications if a number of welding transformers are in use.

In the second case the choking coil is abandoned altogether, and regulation of the current supply is carried out by using a variable resistance in series with the arc, exactly as when dealing with the fixed voltage D.C. welding circuit. In this case the main drawback is that the characteristics of the current supply are not suited to welding owing to the voltage wave form, and also that a large amount of current is dissipated as heat. One manufacturer of welding plant partly meets these problems by supplying a regulating unit for a welding transformer, which combines a choking coil and a resistance, so that the power factor is increased to about 60 per cent. and the losses in the series resistance are halved.

Plant for Metallic Arc Welding (Multiple Operator). In places where a number of welders are employed the joint cost and upkeep of a number of separate welding plants leads to the necessity for the employment of single plants capable of supplying several operators. When direct current is employed for welding, the simplest and best plant is the fixed voltage (60 volt) generator supplying a number of welding circuits each with its own regulating resistance, and, if necessary, its choking coil. If these circuits are connected in parallel as many welders can be placed in circuit as the capacity of the generators will allow. Large numbers of such units have been made in recent years with generators having a capacity of 1,000 amps., which is sufficient to supply eight welders on ordinary welding work.

When A.C. transformers are used, the simplest plan is to instal three-phase to three-phase transformers, each of the three secondary circuits supplying one welder. A certain amount of balance is thus kept on the load between phases and the cost is kept within reasonable limits.

Atomic Hydrogen Welding. This process, which originated in the United States of America, is of recent origin, but promises to have a number of useful applications. In it an alternating current arc is maintained between two tungsten electrodes, and a stream of hydrogen gas is blown through the arc core, the high temperature of the arc completely dissociating the mass of gas in contact with it. This dissociated, or atomic, hydrogen diffuses from the core to the cooler regions, where it recombines to the molecular state. In doing so the hydrogen gives up the energy which it has previously absorbed from the arc and produces, at a spot about half an inch in front of the tungsten arc, a small zone of extremely high temperature (3,700° C.). This hot spot is used for welding very much as in oxy-acetylene welding, a filler rod of uncoated wire providing the necessary welding material.

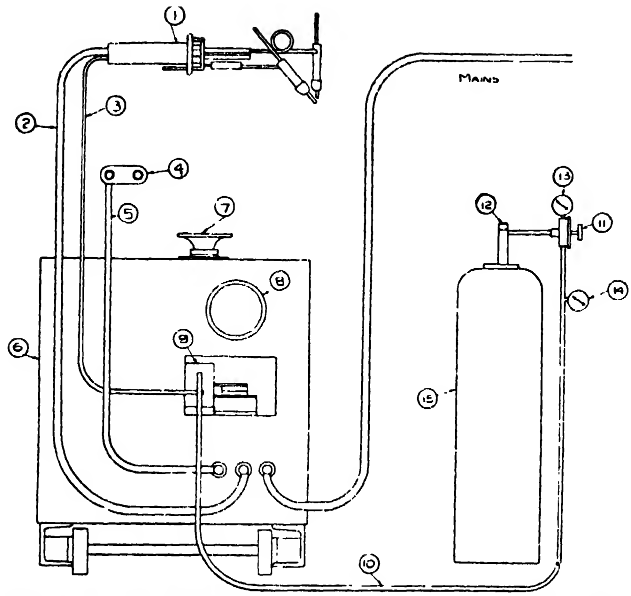
The A.C. arcs used in this process are fairly long and take the form of a fan between the tips of the tungsten electrodes. There is usually about 90-volt drop across the arc, and the open circuit voltage required to maintain it is about 300.

The lay-out of the plant is shown diagrammatically in Fig. 4. As the atomic hydrogen plant, like the ordinary A.C. arc welders, uses a single-phase supply, out-of-balance loads are created on three-phase circuits, and modified plant has been recently introduced to correct this. In this plant three tungsten electrodes are used instead of two, so that a three-phase instead of a single-phase arc is created.

PRESSURE OR RESISTANCE WELDING

In this process an alternating current of high ampèrage (up to 50,000 amps.) and low voltages is passed through the parts to be welded, these parts being brought close up to one another and held in special holders before welding commences. At the point of contact of the two parts being welded a considerable amount of heat is generated and the current is passed long enough to allow of a welding temperature being attained (generally a white heat). The current is then switched off and mechanical pressure applied, consolidating the material and making a sound weld.

Electric resistance welding machines are divided into three main groups,



WELDING. Fig. 4. Lay-out of plant. 1. Torch. 2. Torch cable. 3. Torch gas tube. 4. Push-button box. 5. Push-button cable. 6. Welding set. 7. Control handwheel. 8. Ammeter. 9. Auto hydrogen valve. 10. Gas tube. 11 Auto regulating valve. 12. Hydrogen cylinder valve. 13 and 14. Pressure gauges. 15. Hydrogen cylinder.

depending on the type of operation which they are designed to perform, as follows:

(1) Butt welding machines.
(2) Spot welding machines.
(3) Seam welding machines.

In all these machines the power supply must be alternating, so that where only direct current is available a rotary converter or motor generator must be used. For loads up to 15 kilowatts the rotary converter is satisfactory, but for higher loads it is preferable to put in a motor generator, as the latter machine permits of overloading while the former does not.

Each welding machine contains its own transformer as an integral part of the machine, and as the secondary winding must carry high current at very low voltages it must be very massive. In fact, it often consists of a series of copper or gunmetal castings, and may have only one turn round the core of the transformer.

Butt Welders. In this form of machine, which is shown diagrammatically in Fig. 5, the parts to be joined are clamped in two jaws forming the terminals of the secondary winding, contact being maintained either by automatic means or hand pressure. When a high enough temperature has been reached the metal becomes plastic, and the two ends are forced together, thus forming a sound weld. This method is called "slow upset" welding.

When welding thin metals, however, difficulties are experienced with this method, and what is known as the "flash" welding system was introduced, which allows of all types of material being undertaken quite easily. The only difference is in the application of the current. With the "slow upset" method the parts are lined up in contact, pressed together, and the current then switched on. In "flash" welding the current is switched on before the parts make contact. They are then brought slowly together, and when they just make contact an arc starts to form and continues until the two ends are incandescent and above welding temperature. The ends are then rapidly forced together and the current switched off. In addition to giving better all-round results, "flash" welding saves as much as 50 per cent. current.

Spot Welders. The parts to be welded are placed between and in contact with two pointed or other shaped copper electrodes. Each electrode is connected to one terminal of the secondary winding of the transformer, and when the current is switched

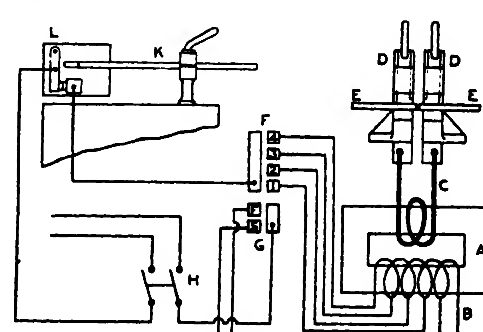
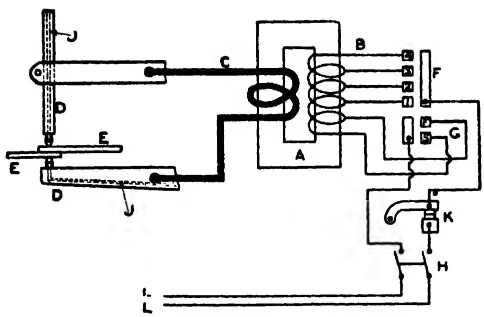


Fig. 5. Lay-out of butt-welding machine. A. Magnetic circuit. B. Transformer primary winding. C. Transformer secondary winding. DD. Clamps for holding work to be welded. EE. Material to be welded. F. Plug box stops, 1, 2, 3, and 4. G. Plug box stops, fast and slow. H. Main switch. K. Automatic trip rod. L. Automatic cut-off switch.



WELDING. Fig. 6. Connexions of spot welder. A. Transformer, magnetic circuit. B. Transformer, primary winding. C. Transformer, secondary winding. DD. Electrodes. EE. Material to be welded. F. Plug box, 1, 2, 3, 4. G. Plug box, fast and slow. H. Main switch. JJ. Water cooling. K. Auto trip switch. LL. Source of single-phase A.C. supply.

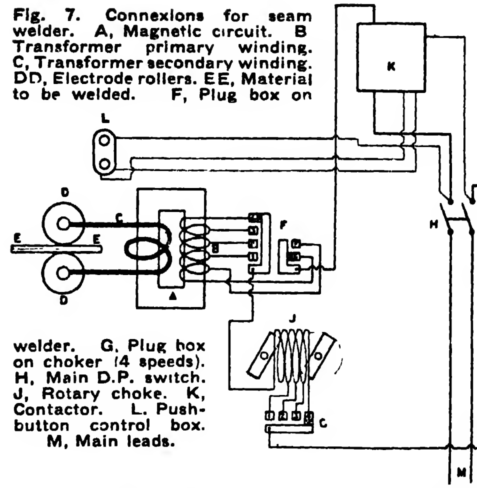


Fig. 7. Connexions for seam welder. A, Magnetic circuit. B Transformer primary winding. C, Transformer secondary winding. DD, Electrode rollers. EE, Material to be welded. F, Plug box on welder. G, Plug box on choker (4 speeds). H, Main D.P. switch. J, Rotary choke. K, Contactor. L. Push-button control box. M, Main leads.

on the metal between the electrodes heats up till it is sufficiently plastic to allow of a weld to be made by pressing the electrodes together (Fig. 6). In order that the electrodes may be renewed as they wear away, the tips are renewable, and are often made of special metals which, in addition to being of high conductivity to enable them to carry the current without overheating, are also resistant to wear and burning. The electrodes are always arranged so that cold water may be circulated through them, which also increases their life.

Mild steel can be economically welded up to 0·75 in. in added thickness, but above this the electrodes are too expensive and the wolding is uncertain, and the indentation caused by the electrodes pressing into the softened plate may become so big as to spoil the weld.

Seam Welders. When overlapping pieces of plate or other material are welded by the spot processes, the finished result will not be watertight unless the spots are made to overlap one another. This is a difficult and lengthy process, and special machines known as seam welders are used when the seams of drums, etc., are being welded.

The seam welder is similar in construction to a spot welder, but instead of passing the work between two pointed electrodes it is pressed between two power-driven discs. Two water-cooled copper discs are connected, one with each end of the secondary winding of a transformer (Fig. 7). Electric current passes between these discs, and welding is caused by pressing the discs together all the time the work is passing through them. To prevent the work from reaching too high a temperature, and thus burning, the current is switched on and off at regular rapid intervals by means of a power-driven switch. By this means the equivalent to a series of overlapping spots is obtained.

In the diagram, this power-driven switch is replaced by a choking mechanism which gives the current a regular pulsating

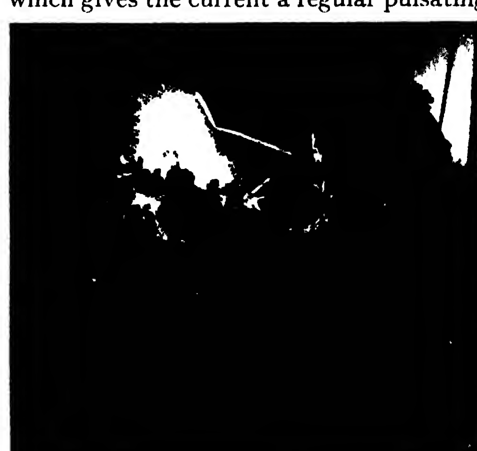


Fig. 8. Example of welded top-plate of a round tank circuit breaker. Fig. 9. Welding with metallic arc.
Ferguson, Pailin, Ltd.

effect, and is the patented method of construction used by British Insulated Cables, Ltd., in their make of machines. In this machine the electrodes rotate intermittently, making 5 to 12 steps per inch of circumferential movement. The pulsations of current synchronize with these steps, and is arranged that when the electrodes are standing still the highest current is applied, and while they are moving the current is reduced so much that the metal between the rollers does not reach welding temperature, and hence does not burn or stick to the rollers. Added thicknesses up to $\frac{3}{8}$ in. can be welded by this process.

All the above pressure welding processes are chiefly applied to mass-production methods, and the principal articles manufactured by them are as follows:

Butt Welding. Wire joining, car and cycle rims, hooped metal casements, steel pipes and flanges, cutlery, motor valves, etc.

Spot Welding. Metal toys, culinary instruments, metal containers of all kinds which are not required to be watertight.

Seam Welding. Steel barrels, drums, hot-water boilers, jugs and kettles.

WESTON CELL. Alternative name for the cadmium cell, adopted as a standard of electrical pressure by the International Conference of Electrical Standards held in London in 1908, and fully described under the heading Cadmium Cell.

WET BATTERY. *See* Battery.

WHEATSTONE BRIDGE. Device for measuring an unknown resistance by means of a known resistance. It consists of a network of six conductors joining four points, and was invented by S. H. Christie, of the Royal Military Academy at Woolwich. Sir Charles Wheatstone pointed out the immense importance of the device to electricians, and it has come gradually to bear his name, though he gave the credit to Christie.

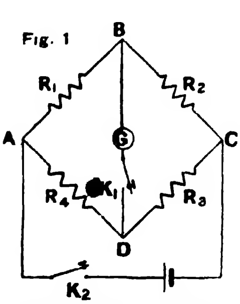
Fig. 1 shows the circuit diagram of the usual form of Wheatstone bridge. R_1, R_2, R_3, and R_4 are four resistances joined as shown at the points A, B, C, D. From B to D is a conducting path which can be opened or closed by a key, K_1, and which has a galvanometer in it. From A to C there is a conducting path with a battery key, K_2.

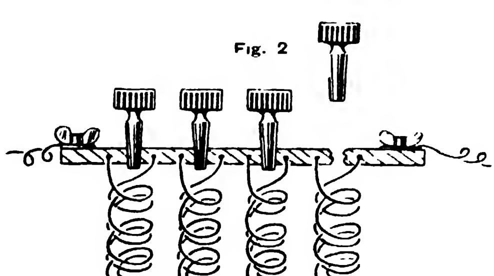
Suppose the key K_1 is open and the key K_2 is closed. Then a current from the battery will divide at A, part of it going along A B C and part of it along A D C. There will be a fall of potential from A to C, but since in the two branches A B C and A D C the fall is the same from A to the point C, there will be a point in A D C at which the potential is the same as that of a selected point in A B C. Suppose the point B is selected in A B C, and suppose the potential at some point D in A D C is the same as that at B. Then if the points B and D are joined by a conductor in which there is a galvanometer, no current flow will be indicated, the pointer of the galvanometer not deflecting.

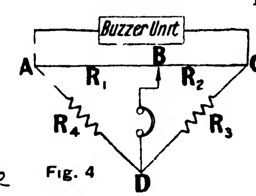
Now the differences of potential between A and B and between A and D are the same, since B and D are at the same potential; and the differences of potential between B and C and D and C are the same. So we can write down the following equations:—

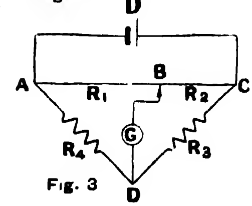
P.D. between A and B = P.D. between A and D, and P.D. between B and C = P.D. between D and C.

If I_1, I_2, I_3, I_4 are the currents in R_1,









WHEATSTONE BRIDGE. Fig. 1 (left). Circuit diagram of common Wheatstone bridge. Fig. 2 (centre). How plugs and resistance wires are used in the Post Office type. Fig. 3 (lower, right). Modification known as the slide-wire bridge. Fig. 4 (top, right). Adaptation to wireless A.C.

R_2, R_3, R_4 respectively, we can write these two equations down as

$$I_1R_1 = I_4R_4$$
$$I_2R_2 = I_3R_3$$

or, dividing one equation by the other,

$$\frac{I_1R_1}{I_2R_2} = \frac{I_4R_4}{I_3R_3}$$

But as the galvanometer current is zero the current in A B, *i.e.* I_1, is equal to the current in B C, *i.e.* I_2; similarly, I_4 equals I_3, so that

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

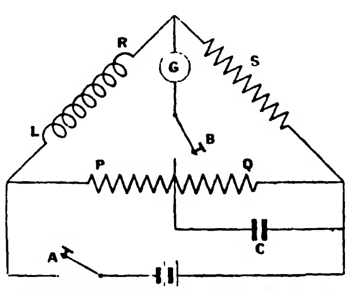
From this equation it is clear that if the resistances of three of the arms of the bridge are known, the resistance of the fourth may easily be calculated, or if the resistance of one conductor adjacent to the unknown resistance is known, and the ratio of the other two resistances is known, the unknown resistance can be found. The resistances R_1, R_2, R_3, R_4 are generally known as the arms of the bridge and D B as the bridge wire.

It is usual in practice to have the two resistances R_1, R_2, called the ratio arms, fixed and in a decimal ratio to one another, *e.g.* 1,000 ohms to one ohm, or 10,000 ohms to 100 ohms, and so on, while the resistance R_3, the measuring arm, is variable, and R_4 is the resistance to be measured.

The unknown resistance is inserted in the circuit, and R_3 varied until the galvanometer reading is zero, when R_4 can be calculated.

A common form of Wheatstone bridge is that known as the Post Office pattern, shown in Fig. 2. In this well-known pattern there are a number of coils of known resistance arranged so as to form three arms of the Wheatstone bridge. The ends of the coils are fastened to solid brass blocks separated from each other, a portion of each gap having a circular conical hole made in it, into which conical brass plugs can be inserted. Fig. 2 will make this internal construction clear.

When a plug is inserted it is clear that that particular resistance coil is cut out of the circuit, the current passing from one brass block to the next through the plug, so that the removal of a plug increases the resistance of the circuit. The coils, it will be noticed, are non-inductively wound. The top of the box is of ebonite and the brass plugs have ebonite tops. In the Post Office type the ratio arms consist of eight coils having resistances of 1, 10, 100 and 1,000 ohms, while the measuring arm consists of sixteen coils of 1, 2, 3, 4; 10, 20, 30, 40; 100, 200, 300, 400; 1,000, 2,000, 3,000 and 4,000 ohms, so that with all the plugs withdrawn there is a total resistance of 11,110 ohms in this series of coils. By withdrawing two plugs in the ratio arms any decimal ratio from 1,000 to 1 may be obtained.



WHEATSTONE BRIDGE. Fig. 5. Use of bridge for measuring inductance. P, Q and S are non-inductive resistances. Key A should be closed before key B to obtain steady balance. If condenser C be adjusted until galvanometer G does not kick when A is closed after B, then constants of opposite arms will be equal.

On the left of where the ratio joins the measuring arm is the galvanometer terminal, on the right the battery terminal, and below the resistance terminals for the insertion of the unknown resistance.

Fig. 3 shows another arrangement of the Wheatstone bridge, often known as the slide-wire bridge. Here a uniform resistance wire A B C has a sliding contact, B, connected to the galvanometer. The circuit is identical with that shown in Fig. 1, and has been lettered in a corresponding way. By sliding the contact B along the wire we can obtain the balance when no current passes through G, and we get, as before, $R_1/R_2=R_4/R_3$. The ratio R_1 to R_2 is the same as the ratio of the lengths of A B to A C, so that if A B has a divided scale attached to it and R_3 is known, R_4 may be found.

Use of Wheatstone Bridge for Measuring Inductance. The inductance of a coil means the number of lines of force induced in it by a unit current circulating round the coil, multiplied by the number of turns of the coil; that is, by the number of times the circuit encloses those lines of force. Experimental methods of determining this quantity are nearly all based on a modification or adaptation of the Wheatstone bridge.

The resistances have first to be balanced,

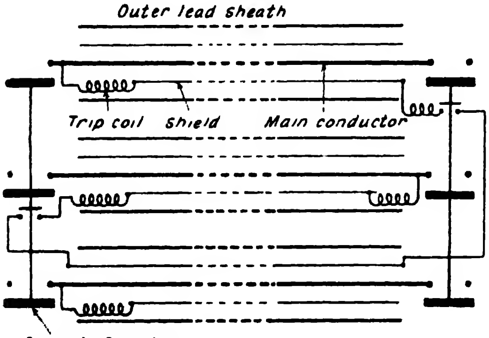
in the ordinary way, under conditions which enable the current to have a steady value. And then the current is made to vary, so as to exhibit the disturbance of the balance due to the inertia or inductance of the coil; that is to say, its choking effect on a varying current.

The simplest mode of varying the current is a make-and-break arrangement, in which case a galvanometer can be used, preferably a ballistic galvanometer (*q.v.*), to measure or indicate the momentary impulse or disturbance. An absolute measure can be got with a ballistic galvanometer, but the more usual method is to make compensating adjustment, so as to reduce the momentary disturbances to zero.

Another plan, used in comparison and null methods, is to vary the current sinuously, as by a vibrating reed or rotating armature, with a rapidity sufficient to give a musical note; and then a telephone is used as the detecting instrument in the cross-arm of the bridge instead of a galvanometer.

Further modifications and applications of the Wheatstone bridge principle will be found described under Bridge (*q.v.*). *See also* Anderson's Bridge; Carey Foster Bridge; Schering Bridge, *etc.*

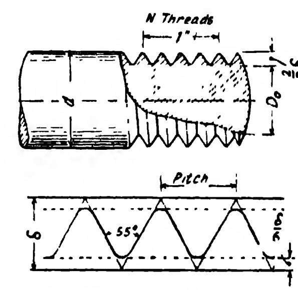
WHITTAKER PROTECTIVE SYSTEM. A system of feeder protection employing separate copper shields and lead sheaths to each phase, with the trip coils connected between the shields and the cores. Normally the shields and their respective cores are at the same potential, but on the occurrence of a fault, current flows from the core through the shield to earth *via* the trip coil and the circuit breaker operates. The insulation between core and shield is considerably reduced from that between the shield and the outer lead sheath, which must be capable of withstanding full pressure to earth, the trip coils being insulated to withstand the same.



WHITTAKER PROTECTIVE SYSTEM. As applied for protection of feeders, the trip coils being connected between core and shield.

The system may be applied to bus-bar and switchgear as well as to feeder protection, the chief disadvantage being the manufacturing difficulty of producing a satisfactorily insulated sheathed cable for high-tension work. For other systems of feeder protection *see* Protective Devices.

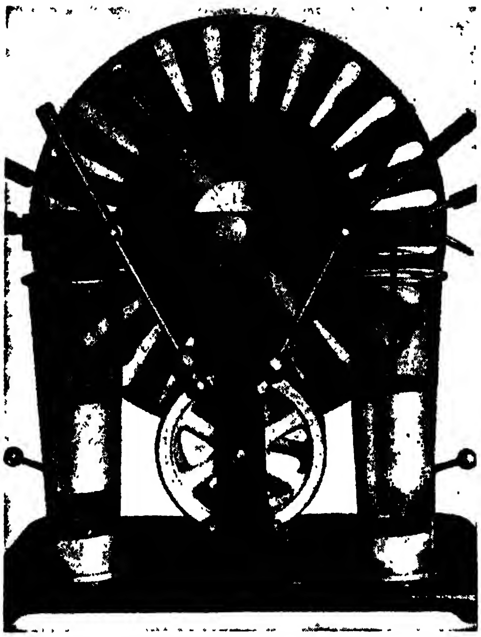
WHITWORTH THREADS. One of the standard forms of screw threads adopted in this country and widely employed in all engineering applications. The relative dimensions are given in the diagram, illustrating the standard Vee thread at an angle of 55°, with one-sixth of the depth rounded off at top and bottom, the depth being equal to 0·64 pitch. In the case of square threads the depth equals 0·475 pitch. The thickness of the nut is equal to the diameter of the bolt, whilst the width across the flats of the nut equals $1\frac{1}{2}$ diameter + $\frac{1}{8}$th inch.



WHITWORTH THREADS. Dimensions and angles of standard thread. δ is angular depth of thread, d the diameter of the bar, D_0 the internal diameter of the nut.

For tables of Whitworth's threads and comparison with other standard forms *see* Screw Threads.

WIEN BRIDGE. An A.C. bridge network for the measurement of the capacitance and effective A.C. insulation resistance of a condenser. In this network the condenser under test is connected on the one side to a standard resistance and on the other to a standard condenser in series with an adjustable high resistance. The fourth arm of the bridge is an adjustable resistance, and a vibration galvanometer is joined to the terminals of the fixed and variable resistances. When the bridge is brought into balance, as shown by a null reading on the galvano-



WIMSHURST MACHINE. This photograph gives a clear view of the variable spark gap fitted with insulated handles, which enables the length of the spark to be regulated while the machine is being operated.

meter, the capacitance and effective insulation resistance of the condenser under test can be calculated from the values of the components of the bridge network. *See* Bridge.

WIMSHURST MACHINE. Name given to a particular type of apparatus employed for experimental purposes in connexion with static electricity. Essentially, the instrument consists of two insulated plates set on a common spindle and capable of revolving at high speeds in opposite directions. Around the circumference of the plates a number of segments of tinfoil are pasted. The current induced between the opposing sections in opposite segments is picked up by means of metallic arms fitted with soft brush contacts.

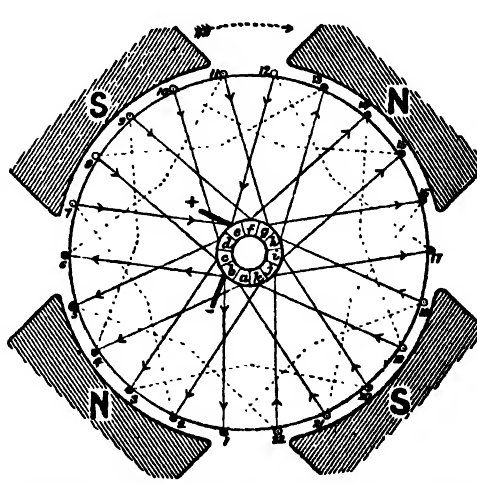
Two or more Leyden jars are usually incorporated to give intensity to the spark, with a variable spark gap fitted with insulated handles, so that the length of the spark may be regulated while the machine is in operation.

WINDING. The active current-carrying conductors of a piece of electro-magnetic apparatus such as an electro-magnet, a dynamo, a motor, a transformer, etc. *See* Armature; Coil and Coil Winding; Conductor; Copper; Rotor; Stator, *etc.*

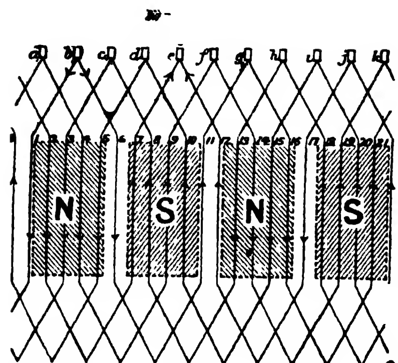
WINDING DIAGRAM. In the same way that a blue-print conveys to the wireman or electrician the exact connexions of a circuit, the winding diagram provides the armature winder with a diagrammatic representation of the type and nature of the winding and the course of the circuits through the armature. The whole scheme of winding is, of course, worked out beforehand and the results may be recorded in a winding table, which is perhaps the simplest way of issuing instructions to the workshop.

Winding diagrams, however, give the designer a much better grip of the problem and enable him to see more clearly the effect of his combinations. There are several methods of drawing out such diagrams. The principal methods may be conveniently referred to as (a) the end-view; (b) the developed; and (c) the radial. The three types are illustrated in the diagrams. It must be emphasized that such diagrams make no attempt at correct scale or exact relative positions, but merely illustrate the scheme of winding.

An example of (a) is given in Fig. 1, showing the end-view diagram of a four-pole wave winding. The front or commutator end connexions are shown with full lines, and the back connexions at the other end with dotted lines. This particular diagram shows how with a



WINDING DIAGRAM. Fig. 1. End-view diagram of a four-pole wave winding.



WINDING DIAGRAM. Fig. 2 Developed diagram of a four-pole wave winding.

multipolar wave-wound machine it is possible to arrange the connexions so that only two brushes are required (*see* Wave Winding).

The developed diagram for the same machine is shown in Fig. 2. This is obtained from Fig. 1 by supposing the cylindric surface of the armature, as viewed from the inside, to be divided between conductors 1–22, and then unrolled and laid out flat, with its conductors lying on it in their proper places. The four polar surfaces appear as a background, and the end connectors are laid out as sloping lines on the same flat surface. The commutator bars appear in section at the top of the diagram, and the positions of the two brushes are indicated by — and + signs.

The radial form is illustrated in Fig. 3. In this form the active conductors are shown as short radial heavy and numbered lines between two concentric circles, and the commutator bars appear between two inner concentric circles. The connectors at the commutator end are shown in the annular space between the commutator and the active conductors in the polar gaps, which are shown wide for clearness.

WINDING FACTOR. *See* Spread Factor.

WINTER-EICHBERG-LATOUR MOTOR. A repulsion motor (*q.v.*) in which power factor is improved by feeding the brushes from a transformer secondary, the primary being in series with the stator By tappings easy starting is facilitated. Such motors are extensively used for traction.

WIPE CONTACT. Any contact in which one surface slides over another during whole or part of the time of contact may be termed a wipe contact. *See* Contact Surfaces.

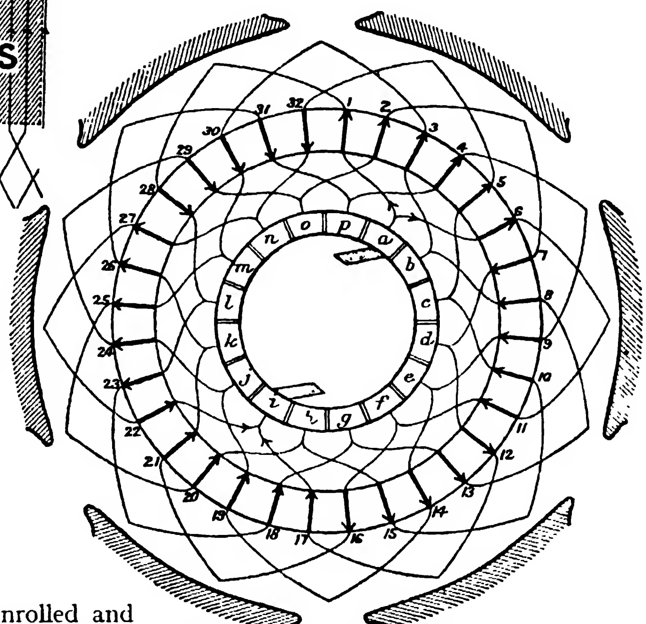


Fig. 3 Radial diagram of a six pole wave winding.

WIRE. Many forms of wire are employed in electrical work, ranging from the fine wire thread used in instruments to the relatively large strands which compose a stranded cable. Copper and aluminium are the materials commonly adopted, but certain special forms of wire are utilized for specific purposes, as described under Resistance Materials (*q.v.*).

Wire is generally sold by gauge numbers. The British Standard Wire Gauge (*q.v.*) is the legal gauge in Great Britain. Details of the various sizes of the respective gauges may be found under the headings A.W.G.; B.W.G.; Gauge; S.W.G., *etc.*

Accurate data regarding the resistance, weight, and usual thickness of cotton insulation of standard copper wires are given in the table on page 352. The sizes of round wires given are those usually employed in dynamo work. Sizes of wire smaller than a No. 16 are rarely employed in machines of any size, and larger wire than the No. 8 becomes unwieldy, and copper strip is resorted to for heavier

sections. For strip windings for armatures, the copper is usually bent to shape by the manufacturer bare, and taped in a taping machine with cotton tape for use, though for armature work laminated copper strips are often employed, and in this case the conductor will be braided with cotton braid about 25 mils thick, as the ordinary cotton covering is not sufficiently tough for heavy copper bars.

House Wires. The conductors used for house wiring are either solid copper wire, or, in the case of larger conductors, a number of wires stranded together, tinned on the surface in order to prevent the insulation with which they are in contact from corroding them, and enclosed in a layer of vulcanized indiarubber or other insulating material. Upon this is wound one or two layers of insulating tape, and the whole is then braided over and proofed with insulating compound to protect it from moisture. The sectional area of any copper conductor should not be less than that of a No. 18 S.W.G. wire, and single wires should not be used in sizes greater than No. 14 S.W.G., as wires smaller than No. 18 are liable to accidental fracture, even inside the covering, while being installed, and wire larger than No. 14 may be damaged if bent at too sharp an angle.

Conductors of greater sectional area than No. 14 S.W.G. should consist of smaller wires stranded together to form a cable; in this way greater flexibility is obtained, and for this reason it is good practice to use none but stranded conductors in house wiring.

The cooling surface in small wires is much greater in proportion to the section than in large ones, and for this reason small wires can carry more current per unit of cross-sectional area than large ones for a given rise of temperature. The current-carrying capacity of conductors is discussed both under the headings Conductor, Current-Carrying Capacity, and also under Fuse (*q.v.*). *See also* Aluminium; Cable; Copper; Flexible; Joints, *etc.*

WIRED WIRELESS. A system by which intelligence is transmitted over wires by means of high-frequency currents, tuned circuits being used at both sending and receiving ends as in radio communication. The high-frequency currents are modulated according to the signal or speech frequencies to be conveyed and act as a means of carrying the low-frequency variations in the same manner as the high-frequency carrier waves in radio transmission convey the modulation frequencies.

The particular advantage of such a system over ordinary telegraphy or telephony is that a number of separate and distinct messages can be sent simultaneously on separate carrier-frequency currents, being selected at the receiving end by tuned circuits. The system has not come into very general use because of the attenuating effects of lines on H.F currents.

WIRE GAUGE. *See* British Standard Wire Gauge; Birmingham Wire Gauge; Brown & Sharpe Wire Gauge.

WIRING AND ITS PRACTICAL APPLICATIONS

By Donald Smeaton Munro, M.I.E.E.

After dealing with the various rules and regulations which govern wiring, the following pages attempt to give the student or the general reader a short but comprehensive survey of the several ways whereby wiring is commonly applied for practical purposes. Incidentally, most of the chief difficulties encountered by the designers and fitters of wiring are indicated and the approved means of making installations safe are described. See also Buildings, I.E.E. Regulations; Cable; Conduit and Conduit Systems; Copper; Current Capacity; Joints; Lighting Fittings; Wiring Regulations, etc.

The electrical industry now ranks as one of the chief of the world's occupations and wherever there are electrical appliances some wiring is necessary. Electrical wiring and installation work is of the greatest consequence as it is the most universal requirement of the industry. The fact that wiring work has to do with the infinite ramifications of electricity on the credit side of the meters in itself raises the subject to the peak of importance when money counts for so much. The

varied and increasing number of manufacturing processes also connected with installation materials and the number of fitters thereof substantiate the boast that the installation section regularly employs a greater number of skilled electrical workers than any other in the industry. The way in which systems and appliances elude the standardization experts is further proof of the irrepressible activity of this sometimes lightly despised but most vital branch of electrical engineering.

The coming of the "Grid" in Britain has brought a host of new wiring difficulties yet to be solved in a satisfactory way. Short-circuit values have grown greatly with interlinked stations, heavy mains and the bigger capacities of installations due to the free use of cookers and heaters. The effects of surge currents have to be guarded against and also the increased dangers owing to final standard A.C. pressures of 230 and 400 volts.

The comparatively recent introduction of ranges of moulded insulating materials, such as bakelite, has given a new orientation to designers of wiring appliances, and some encouragement to those who set their hopes on "insulation" rather than "earthing" as a safeguard.

The effective life of these materials, however, under practical conditions and subject to electrical stress, has yet to be ascertained, and we must keep in mind that in our humid climate, and especially in definitely damp places, water or even a slight film of moisture over a synthetic resin insulating component annuls its comparatively mild insulating qualities and is quite effective in conveying shock (*see* Plastics; Synthetic Resin).

All approved public supply now has a neutral or earthed wire, consequently the greatest safety is attained when the coverings of appliances liable to become "live" are also earthed. The question of earthing on installations is associated with "cut-out" protection and it is likely that the next few years will witness a greater tendency towards the adoption of small automatic cut-outs (*see* Miniature Circuit Breakers) in place of the slower acting and somewhat more unreliable method of fuse protection.

The extension of rural work has increased the field of application for small electromagnetic devices.

Wiring Rules

The I.E.E. Regulations. At the beginning the insurance people in this country took a proper active part in the regulation of wiring and, outstandingly, the early rules of The Phœnix Assurance Co. did much to direct pioneer electrical work on sound lines. For a long time after 1882 (in which year the Institution of Electrical Engineers published the first edition of their "Rules and Regulations for the Prevention of Fire Risks arising from Electric Lighting") the Phœnix Co. continued to issue their own particular and in many ways superior directions. Now practically all the insurance companies, including the Phœnix, have nominally the I.E.E. regulations, but make little effort to enforce them. Since 1924 these have borne the official title of "Regulations for the Electrical Equipment of Buildings" (*see* Buildings, I.E.E. Regulations *and* Wiring Regulations).

In spite of the sometimes conflicting interests, and possibly owing to the skill of the editing sub-committee, the I.E.E. Regulations constitute a very fair general guide to good average practice and there are now available to earnest wiremen several simplified interpretations of these regulations. It is, perhaps, unfortunate that the regulations have of necessity to deal at greater length with the best and most complete systems such as screwed conduit. The minor and inferior methods, with comparatively little space devoted to their restrictions, have thus by a negative virtue of the regulations acquired since the war period a commercial impetus sufficient to ensure the bulk of housing schemes being made less safe for democracy.

The I.E.E. Regulations cover the range of methods of wiring to be described and their compilers state as a preliminary that some are more suitable than others for a given set of conditions, but no system is most suitable for all conditions. Safety from fire or shock is obtainable by any one of the systems, they say, provided that it is selected according to working pressure, atmospheric conditions, class of building and size of installation.

It is very necessary for those who practise wiring to make themselves quite familiar with the details of the I.E.E. Wiring Regulations, and copies can be

obtained at the offices of the Institution, Victoria Embankment, London, W.C.2 (1s. 2d. post free). They are further considered in pages 155–56 and under Joints, and extracts from the 10th edition are also given the heading Wiring Regulations itself.

The importance of the I.E.E. Regulations is evident from the fact that not only the insurance companies, but the National Register of Electrical Installation Contractors have adopted them, and in "The Supply Regulations of 1934" the Electricity Commissioners have now given these particular regulations the widest general application.

Rules for Factories and Places of Entertainment. For factories there are the appropriate "Regulations for the Generation, Transformation, Distribution and Use of Electrical Energy in Premises under the Factory and Workshops Acts," also put forth by the Home Office. These are interestingly annotated at great length by the Senior Electrical Inspector of Factories (*see* Home Office Regulations).

In 1923 the Home Office also issued "Electricity Regulations for Cinematograph Theatres," and the work in all picture houses must now conform to these requirements. The various H.O. regulations are obtainable from H.M. Stationery Office, or through any bookseller.

The London County Council have also drawn up a set of rules and regulations for places of entertainment. These L.C.C. rules have been widely adopted in other districts. It is often difficult to interpret the specific electrical requirements of County Council authorities, and it is sometimes hard to obtain their presumably skilled opinions, official sanctions and necessary certificates. A recurring clause "as the Council may consider necessary," has no doubt justified some inspectors holding up quite a few sparkling shows at the last minute. Big stage work has now chiefly drifted into the hands of a few firms who know the L.C.C. ropes thoroughly. Others, it is feared, sometimes find compliance with the vague but insistent requirements of Council theatre inspectors rather analogous to squaring the circle. In spite of all the bureaucratic safeguards or obstacles, it is not often that anyone acquainted with the subject is impressed with the high quality of the wiring details evident in places of public entertainment.

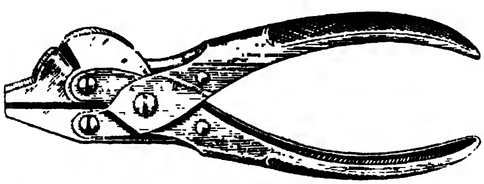
Inspection of Wiring. The necessity for thorough wiring inspection must become more urgent as time reveals the faults incipient in the post-war "go as you please" period. The insurance companies are not very interested in small dwelling-houses, but the County Councils and Corporations are, and they must find that the policy of accepting the lowest tender will involve big outlays for examination prior to replacement.

In America the making of a National Code of Wiring Rules, the selection of materials, and the control of inspection are all in the hands of a Board of Fire Underwriters. The adoption of that system is in the present writer's opinion logical and proper. In Britain only a few insurance companies now retain the services of skilled wiring inspectors. But we have Government departments as the Admiralty, War Office, Home Office, Post Office, etc., all with their quota of more or less qualified inspectors. There is a considerable organization of inspectorship connected with the Factories Act and the Wiring Regulations. Every considerable municipality and supply company has its band of inspectors, and in 1933 the National Register of Electrical Installation Contractors set up its own independent organization to deal with the examination of wiring work. In the near future this big question of wiring inspection must command more comprehensive attention from the industry and from the nation than has hitherto been accorded.

Training of Wiremen. "A fool with pliers in his pocket," was how some very superior electrical engineers were wont to describe the wireman. The description has long ceased to have point. The trained modern wireman can well hold his head up in the confraternity of tradesmen, for his is a long, arduous period of learning before he is fully qualified.

In addition to a thorough grounding in electrical principles he must ever keep up to date by text-book, periodical, class and lecture. He should have the ability to make neat drawings and to interpret plans. The variety of the materials he works in gives him some knowledge of the problems and practices of the

crafts of the builder, blacksmith, carpenter, plasterer and decorator. His is not a periodic trade, there is work for the first-class wireman all the year round, and there is in it the spice of great variety.



WIRING. Fig. 1. Combined cutting pliers and wire-puller.

He is familiar with machines and their operation, but is rarely, like the factory hand, tied to the monotonous workshops for very long. Chiefly his jobs lie in the towns, but there are chances of pleasant breaks in the country and occasionally opportunities for finishing off installations during trial trips at sea. A father considering a career for his son may still favourably regard the rôle of wireman or installation engineer. There is no doubt that the best approach is through apprenticeship in a good contracting firm, accompanied by a course of evening classes. If beforehand he has a technical college diploma or a degree in science it is, of course, all to the good in increasing his usefulness, and perhaps his salary, later on. Even in the worst periods of trade depression it has been proved that the really dependable installation engineer rarely lacks employment.

The comparatively easy way of entering the trade by being taken on as an improver or wireman's mate has perhaps increased in some areas, but is not so thoroughly well adapted as the apprenticeship method to give the best results, although, of course, much depends on the individual, and it takes a lot to keep back the man who, not having earlier chances, is determined to acquire the requisite knowledge and skill.

Wiring Methods

Wiring methods may be separated into two main classes—those which have an insulating material as the outer protector and those in which the covering is of metal.

In the first class are wood casing and capping; tough rubber sheathing; china insulator systems and the like. Steel conduits, lead-covered cables and copper-covered cables are typical of the second category. Detailed descriptions of methods in both divisions are given under their own headings in this work, but it is fitting to give here comments on both the principles employed and certain aspects of their application. In all such writings, and especially where comparisons as between types are made, there must be a certain amount of apparent prejudice induced by personal experience. The writer believes, however, that he has stated the case for or against the various methods in a reasonably fair way. Under their individual headings in other pages the details and distinguishing characteristics of the proprietary branches of wiring systems are more particularly described.

Wood Casing. In Britain, but never much on the Continent or in the United States, wood casing had great popularity for wiring. The "National Electrical Code" of America is much less indulgent to woodwork than our I.E.E. Wiring Regulations. In America to-day casing or raceways must be coated externally and internally with two layers of waterproofing and impregnated with a moisture repellant and a barrier of not less than ½ inch must be interposed between cables. Hardwood only is recommended in that country, although the U.S.A. was the chief exporter of soft butternut casing to us in the old free trade days.

Wood casing is still employed sometimes on British ships and in India, but it may now fairly be classed as an obsolete conveyance for wiring. As a pioneer system applied to our well-built older buildings, it was excellent when properly planned and installed. At first the wires of differing polarity were carefully kept wide apart in special grooves, and numerous ingenious bridge devices were used for crossings and at tee branches for the dividing of polarity.

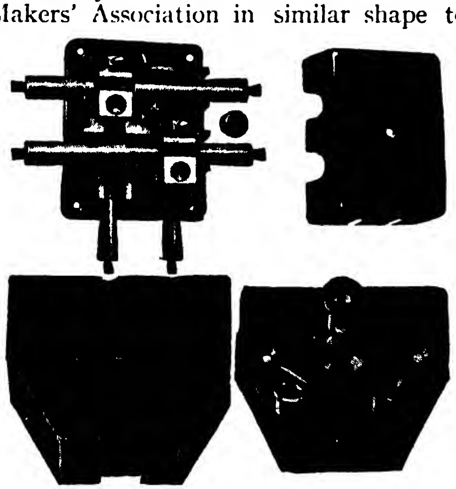
In the original stages the wood casing and moulded capping were of generous proportions. The multiple grooves were nicely calculated to retain the various sizes of insulated cables by the mere elastic compression of the rubber insulation. The casing was mitred and half-checked at tee branches and corners, and

skilfully "dooked" or plugged to walls by conscientious Victorian carpenters, and where extended across ceilings, wood casing was often a work of symmetrical art. The necessity for employing skilled, carpenters as well as electricians for casing jobs often led to disputes and occasionally to mild strikes. Altogether the processes of installing the original wood casing of shellac varnished yellow pine or teak were not cheap, but they were amply justified as they afforded an exceptionally long life to the original rubber-covered cables, and kept them free from all condensation troubles. Later, however, 2- and 3-groove casings and cappings of scanty dimensions were freely imported from abroad, and the growing practice of bunching cables in one groove at last led to a general failure of confidence in wood casing—especially when erected by wiremen with blunt tools.

Tough Rubber Sheathing. Following wood casing in popularity as an insulated outer protector came Cab-Tire Sheathing (*q.v.*). This registered trade name could not be, as such, definitely advertised by the I.E.E. Wiring Rules Committee, so it was officially classified under "Tough Rubber Sheathing."

The credit of ushering in this supremely simple covering for wires belongs to the St. Helens Cable and Rubber Co., Ltd.

This class of cable is now issued by practically all the members of the Cable Makers' Association in similar shape to



WIRING. Fig. 2. Bakelite junction box for single-core T.R.S. cable. Fig. 3. Bakelite tee box, designed for quick wiring.
General Electric Co., Ltd., of England.

their very uniform range of small lead-covered cables for wiring, *e.g.* as single, as twin and as triple core in sizes from 1/·044 to 7/·064 for the single and twin, and 1/·044 to 3/·036 for the triple pattern. It is obtainable in grey or white colours. The protective is especially tough, and the cable may be buried direct in plaster or exposed to surface moisture or sunlight with a fair measure of hope for security. The boxes used with C.T.S. are now generally of bakelite, which may be sealed with a plastic compound for moist situations.

In places where brine and other more corrosive fluids are about or where steam or acid fumes are abundant, this class of cable may most fittingly have those patterns of specially designed china junction, switch and fitting boxes which are provided with sealing channels and chambers filled with oil or with semi-fluid compound. Under such severe conditions the general runs of the wiring are best conveyed on ebonite cleats which space the cables out from the walls. In normal situations it is wise to have fibre saddles rather than the metal variety. C.T.S. cables are very convenient for outside decorative lighting schemes, but probably this robust yet elastic protector of cables fulfils its particular functions best as a covering for flexible cables. Flexibles covered with C.T.S. do not kink readily, and are well suited for vacuum cleaners and other household and workshop appliances. In a thicker form, C.T.S. has proved of great service for use in mines and shipyards for trailing to portable tools.

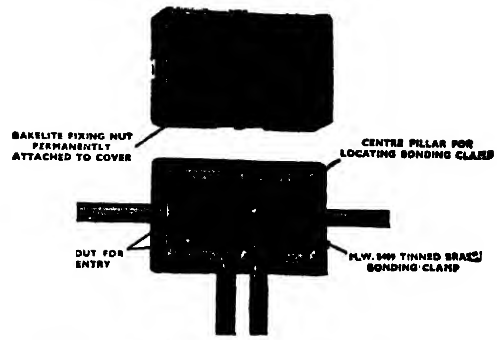
China Insulators. As air is an insulator, bare conductors supported on china or glass insulators may fairly be classed among the insulated systems. Now, however, bare copper wires are seldom employed indoors except for collectors or trolley wires for travelling cranes or for battery connexions. Such exposed wires must only be applied in places not ordinarily accessible to unauthorized persons. Occasionally in farms, factories or places of temporary entertainment insulated wires are run on insulators to the lights and switches. These are generally of cleat form with smooth or rounded edges which will not indent the braiding. The cables used are, as a rule, of V.I.R.

insulation, and when passing through floors or partitions they must be protected by metal or china tubes. If such cables are brought through party walls or fire-resisting floors the holes must be plugged with some non-ignitable material to conform to I.E.E. regulations. Knob wiring, as practised in America, or stud wiring with twisted flexibles, as used in Germany and Italy, never had a vogue in this country, and these transient methods are now rarely employed in the lands where they were originally adopted.

For outside use, such as railway yards, it is now usual to employ cables of the P.B.J. class, which are hard-drawn and have insulation of impregnated paper with lapping and braiding of cotton all well coated with waxy compound. Aerial cables with braiding run cooler in the small sizes, while bare cables are cooler under load in the larger sizes. In the latter case the cover acts as a lagging, and in the former has a radiating effect.

Those who, like the writer, have experimented with enamels as a practical wiring insulation, have been disappointed by their liability to crack or crumble on bending after a few years in use.

Lead and Lead Alloy. Lead seems to possess of all metals certain desirable inert yet ductile qualities and affords a reasonable degree of mechanical protection. Even by the early nineties, however, contractors and consultants had become a little anxious about the composition of the lead and its methods of application. The original lead presses worked at comparatively high temperatures which had no good effect on the pure Para and vulcanized rubber used underneath the lead for insulation. Frequently after the early cables were carefully installed under the best conditions they became afflicted with numerous blow-holes, due possibly to grains of oxides or sulphates embedded in the purer lead. Sometimes it took a few years for these inherent chemical faults to develop their own class of breakdown, but in the interval the weight of lead when supported in clips and its differing rate of expansion from the copper conductor accentuated the susceptibility to fracture. Incipient longitudinal splits and developed blow-holes and transverse cracks were no



WIRING. Fig. 4. Surface wiring junction box for standard lead-covered cable.

General Electric Co., Ltd., of England.

recommendations to the choice of lead-covered wiring method. It was also found difficult to make satisfactory soldered joints to boxes and tee-pieces and to avoid blow-holes when sealing these with soft solder.

With the lead protection great care was requisite to avoid contacts with wood which was likely to get damp, for then the metal in proximity soon became transformed into the crumbling powder of white lead. Dead leaves, wet plaster and walls or flooring containing traces of ammonia were all dangerous in the neighbourhood of lead cables. Lead sheaths were also very susceptible to electrolytic faults (it should be kept in mind that this action requires a potential difference of little more than 1 volt). To guard against this particular trouble the cable was sometimes wiped with vaseline mixed with sodium silicate where laid near other metal pipes. This is obviously an unsatisfactory expedient for everyday wiring.

As was early found with compo pipe, some alloy or mixture of lead with other metals tends to give more strength and cohesion, and chemists all over the world are still evolving composites many of which give improved mechanical properties over pure lead, although it is still doubtful if any such alloy is really more resistant to corrosion.

Lead never had sustained popularity for wiring work until in 1911 Henley's special metal-sheathed system came on the market. This brighter and harder kind of metal cable covering was marked out for favour by the compilers

of the (8th Edition) I.E.E. regulations, and its composition came under the definition of " a covering containing not less than 95 per cent. of commercially pure lead (the remainder consisting of rarer metals)."

The demand for this " special metal " sheathed cable became very widespread and it was soon copied by the other manufacturers, nearly all of whom also issued varieties of light metal stamped boxes and continuity fixtures for use with this smart-looking cable. Although it was primarily to secure a measure of water-tightness and continuity that lead was used for house wiring, nearly all the ranges of junction and outlet boxes did not, and still do not, ensure the first quality and they only inadequately provide the second. The practice of fitting stamped rings and other sketchy bonding devices under wood blocks has very obvious dangers; they are out of sight when in place and the metal is too close to the live parts of connectors, etc., to be quite safe. These objections also apply to the now common bare earth continuity wires now sometimes included under the cable sheathing.

The wiring regulations specify a continuity test for resistance after erection. Few exponents of this class of wiring consistently carry out such tests and fewer still would care to speculate on how long the continuity conditions can remain stable with slight, clamped contacts on a material so soft, yielding and inelastic as lead, especially when oxidation and dust and paint have combined to fill up the numerous free air passages which are features of the characteristic continuity clamps and most of the stamped boxes marketed for lead alloy systems.

Copper Sheathing. Copper, if it be thick enough, would appear to be the ideal outer metallic covering for wiring. Only occasionally in the last half century has the price of copper been so low as in recent years. So, lately, quite a considerable number of installations have been carried out in copper tubing of a gauge comparable to the common steel conduit. To be consistent the junction, draw, and outlet boxes used with copper pipes should be of cast bronze, but the delays consequent in manufacture and price of these special fittings put obvious limits to their general application. There are practical difficulties in the drawing down of stout copper pipes into a solid drawn close sheathing for cables after the manner of the familiar " special metal " systems, and the high cost of early copper strip sheathings which had a longitudinal brazed seam put them very much out of ordinary consideration.

The most extensively used copper-sheathed wiring system is the " Stannos " (*q.v.*). This type of cable is free from most of the faults of lead; sagging, decentralization and crystalline cracking are avoided and it is rodent and vermin proof. The mechanical protection is not so complete as with steel conduit.

Owing to the specially neat appearance and comparatively long life of this make of wire it may form a useful supplement to a first class conduit installation in those parts of a fine building where the wiring must be exposed and where elaborate wall or ceiling mouldings have to be neatly negotiated. This tinned copper covering is obviously specially applicable to use as a concentric system, and is practically the only make of cable now used to any extent in that way in this country.

Wiring Distributive Systems

Constant Current System. This is more than a mere example of ordinary wiring distribution. It is a distinct and generally self-contained electrical system wherein all the lamps or consuming devices are connected in series and demands switches of special design which never completely break circuit.

The constant current series system applied at first to arc lamps is now occasionally used in Britain for heavy auxiliary power purposes in ships and for certain types of crane and haulage plant where it has some advantages in simplification of control gear. When this method is adopted no part of the system should be earthed and it is most important that the insulation of all conductors and appliances be fully maintained against sudden stresses. The operation of all switches must be effected without breaking the main circuit, and when any appliance is switched off it must be entirely dis-

COMPARATIVE TABLE OF DISTRIBUTION SYSTEMS

Name	Diagram	Graphic	Curve	Weights of combined conductors for same resistance loss at same volts				
				P.F. ·95	P.F. ·90	P.F. ·85	P.F. ·80	P.F. ·70
D.C., 2-wire				100	100	100	100	100
D.C., 3-wire				31·2	31·2	31·2	31·2	31·2
Single-phase, 2-wire				105	111	118	125	143
Single-phase, 3-wire				33	35	37	39	45
Two-phase, 4-wire				105	111	118	125	143
Two-phase, 3-wire			do	89	95	100	105	122
Three-phase, mesh or delta				79	83	89	94	107
Three-phase, star			do	79	83	89	94	107
Three-phase, 4-wire, volts between outers and neutral			do.	31	32·5	34·5	36·5	42
Three-phase, 4-wire, volts between outers			do	92	97	104	109·5	

connected on both poles from the system. In America especially, outside lighting in tandem is still employed and there such circuits are generally on A.C. supply, which means in almost all cases that the series circuits are fed through a constant-current regulator. Such a regulation, or alternatively a series lighting generator, maintains a definite current value regardless of the devices inserted in circuit. A great drawback to constant-current systems for indoor use is that the pressures involved are excessive and consequently an accidental break in the circuit is apt to produce vicious and persistent arcing. The advent of the " Grid " in this country has practically disqualified further development in constant-current apparatus, but it is well to have some acquaintance with the peculiar possibilities. On this system the same size of conductor is maintained throughout. A current of 6·6 ampères is the most usual standard and many thousands of volts are generally impressed on such constant-current circuits. Precautions have to be taken accordingly.

Ring Main System. In certain circumstances, to guard against interruption or to maintain a practically constant voltage, it is desirable to plan the feeders for branch wiring on the Ring Main system (*q.v.*). This arrangement is common on town service mains and on battleships and is sometimes applied to factory or large office installations. There is some resemblance to the constant-current lay-out in this method of maintaining constant voltage by means of a pair of ring mains. The generator or other source of energy feeds a pair of cables which individually form a continuous though generally very irregularly shaped ring. Sets of double pole fuses are fitted at the **T** point of supply to the ring and at branches therefrom for distribution fuse-boards. Varying loads onthese fuseboards are compensated for volts drop from either direction on the ring mains. Complete severance of the mains, as by gunfire, a navvy's pick or other cause, does not isolate any distribution fuse box. As electric heating increases in favour there will probably be an increase in this often economical method of arranging feeders for fluctuating loads even in the smaller installations.

Earth Return and Concentric System. Like the ring method the earth return system was primarily associated with ships, and the principles are much the same as those of concentric systems. Single pole fuses are used. The generator feeds the distribution boards by a single positive cable. The negative or " earthed " cable is connected to the vessel's steel hull or to the outer metal sheathing in the case of a concentric system. The live wires are led to the switches, then to the lamps and finally to the ship framework or to the metal concentric cable cover.

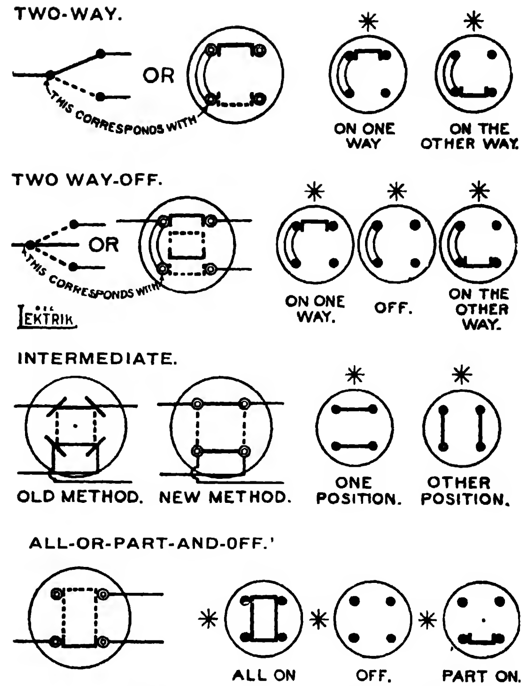


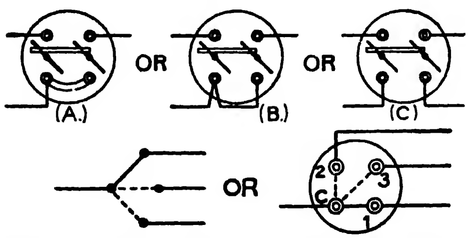
Fig. 5. Representation of switches in diagrams. The symbols starred are not generally used, but represent alternative positive of switch contacts.
A. P. Lundberg & Sons, Ltd.

This principle of wiring is attractive in theory but has not on the whole been very successful in practice. On ships great trouble has been caused by corrosion and chemical action at the numerous hull junctions and by the readiness of the live cables to find unexpected leakage paths. On land work the liability of concentric systems to cause unforeseen difficulties is also considerable. The disabilities are multiplied now that there is so much demand for multiple switch control points on modern installations and when bell or signalling systems and telephones are energized inductively by transformers.

Tree System. This plan of wiring dates also from the genesis of electric lighting in the early eighties. In principle it means that trunk, branches and sub-branches of any constant voltage distributive system are each provided at the root or radiating point with fuse protection. Many of the original wood casing installations were arranged thus and furnished with diminishing sizes of china rectangular D.P. fuses as the circuit reached its final attenuations. In some of the first installations overloads were so finely safeguarded that each pendant or branch switch was arranged also with an S.P. fuse, the positive excess being protected on the switch and the negative in the ceiling rose. A modern recurrence of this primal lay-out is the application of supplementary fuses on a sub-circuit for such delicate appliances as electric clocks and radio.

Distribution Fuse Box System. This is by far the most usual wiring arrangement. It is applied to the smallest County Council house and to the very largest lighting and power installations. In the first example the supply cables generally enter a small service box which contains a pair of sealed fuses. The small main cables then pass on to feed, say, a splitter switch fuse (*q.v.*). That is the name for a small double-pole main switch which, in the same case, contains more than one pair of fuses. From the two or more pairs of fuses branch circuits are led to supply the lamps in the house. There is some risk of these little splitter switches disappearing in one good flash in the event of a short circuit on " Grid " supply networks. That is one reason why larger installations have separate main switches and distribution fuse boxes.

A house or office having, say, 100 or somewhat fewer lamps may be provided with a 10-way fuse box, or it may, more conveniently, have two 5-way boxes or a 6-way and a 4-way box. When there are two or more distribution fuse boxes, it is good practice to provide a main distribution fuse box from which the sub-distribution fuse boxes are indirectly fed. This system has the advantage over the tree layout that fuses are concentrated at easily



WIRING. Fig. 6. Representation of switches in wiring diagrams (Above) Pilot or detective switch, (below) three-way switch.
A. P. Lundberg & Sons, Ltd

located positions. In larger industrial installations and in buildings such as modern hotels, where the main and sub-main cables must carry heavy loads, it is usual to fit automatic cut-outs or circuit breakers (*q.v.*) instead of fuses, and in some cases that alternative form of circuit protector is adopted throughout even to the smallest sub-circuits (*see* Miniature Circuit Breaker).

Balance of Wiring. Most public services are now from 3-phase 4-wire cables, and in the larger towns one house or office is generally balanced against another (*see* Balanced Load, page 106). In such cases the question of balance does not trouble the wireman, for each set of premises is fed by one live cable and a neutral through a simple double-pole main switch and D.P. fuse board.

In most rural districts, however, and for the larger buildings in towns, the services consist of 2- or 3-phase wires and neutral. In such cases it is necessary to allocate approximately equal numbers of lamps, heaters, or other consuming devices over the 2 or 3 phases. Very often the supply authorities give directions as to the division of the phases. In a medium-sized house, for instance, they may direct that all the lights be put on one phase and the heating sockets on another. Here, of course, two D.P. main switches are called for.

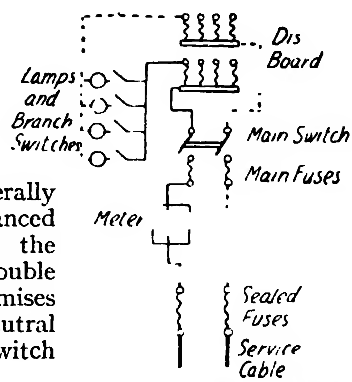


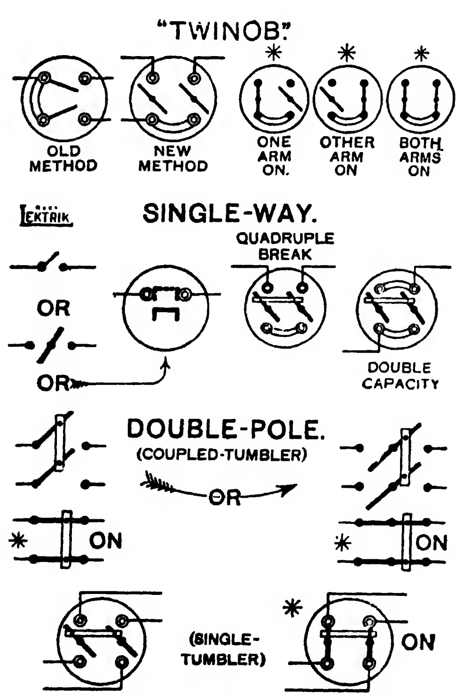
Fig. 8. Simple 2-wire service diagram for distribution fuse system.

For a large building in town, or even for a comparatively small house at the far end of a rural line, they may demand that the lights be divided among the 3 phases and that the power or heating sockets be treated in the same manner. So the formidable minimum of six distribution boards will be required, and if separate main switches and meters are needed for the lighting and the heating, then two each of "3-pole and neutral" type are indicated. Some authorities forbid this type of main switches and demand the fixing of six D.P. switches, three each for lighting and heating.

There is, of course, a much higher pressure between one phase wire and another than there is between any phase wire and neutral. Therefore it is most desirable to keep appliances fed from differing phases far apart. This is often difficult to ensure in practice and indicates the great need for efficient "earth wire" protection on each appliance.

Circuits and Sub-Circuits. In England, now, it is almost standard practice to feed lighting sub-circuits from double-pole (nominal 15-ampère) distributing fuse boxes, and it is advisable that the cables for each circuit should run in separate conduits; this limits possibility of cross-over connexions on the fuse board. These mistakes are more common than supposed and lead to fatalities.

A sub-circuit may serve a maximum of 10 lighting points. Although the smallest fuse bridges in general use are designated 15-ampère size, it may be laid down that



WIRING. Fig. 7. Representation of switches in wiring diagrams.
A. P. Lundberg & Sons, Ltd.

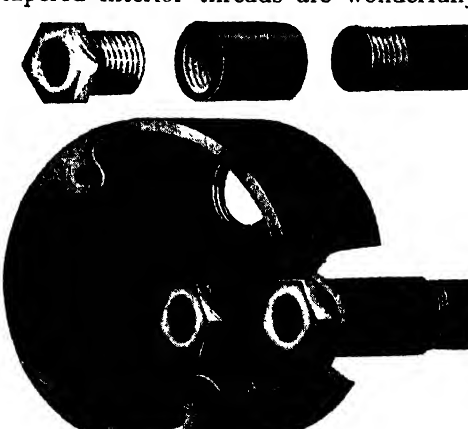
an ordinary house or office circuit should not carry more than 600 watts. Heating circuits for radiators are generally served by D.P. (nominal 30-ampère) distributing fuseboards if more than one 15-ampère outlet is provided per circuit. When tubular or other form of non-radiant heaters are installed, there may be several outlets fed even from 15-ampère size fuses. In some such house or office installations the fuse boxes are provided with small neon lamps which glow when their individual circuits are in use. The added first cost is compensated by the ready indication and disconnexion of wasteful heaters. Wiring methods for heaters or motors are comparatively straightforward compared with lighting or for mixed lighting and heating circuits.

Combined Lighting and Heating Circuits. The popularity of two-part tariffs has led to many buildings having their lighting and heating energy recorded on one meter. Unless the heaters are few and small, it is undoubtedly the right thing to provide separate lighting and power fuse boxes, even if the sub-mains to these meet at the main switch. When only one fuse box is fitted for the sake of economy, definite circuits are best allocated to serve individual heating outlets. In some districts it has become an unwritten rule that these circuits should be at the right-hand of row of fuse carriers. In outlying rural places, where a moderately sized farmhouse is supplied by three phases, it becomes a virtue sometimes to feed the radiators and lights thus from the same fuse box, for this tends to ensure that all the appliances in any apartment are fed from the same phase. The post-war period has brought a great multitude of small houses on to the mains, and in many of these heating and lighting points are fed from the same sub-circuit. The practice can only be defended if the heating point is the first outlet to be fed from the board, and the lights looped on thereafter. Even then the circuits are fit only for small bowl fires and irons. The indiscriminate selling of 2 and 3-unit radiators and wash boilers from showrooms and stores has led to much trouble among small and cheaply wired houses.

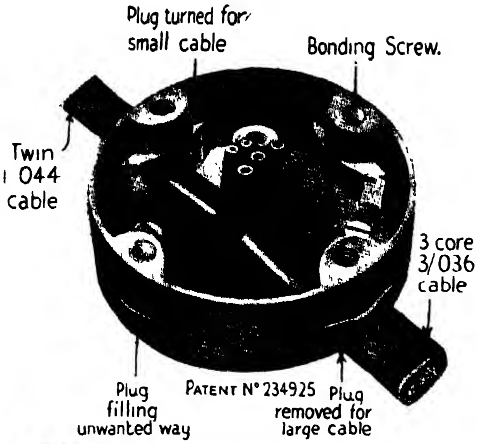
Circuit Box Selection. Joints on circuit wiring have largely gone out of fashion, so joint boxes are now chiefly used as convenient draw-in and passing-through receptacles for looped cables.

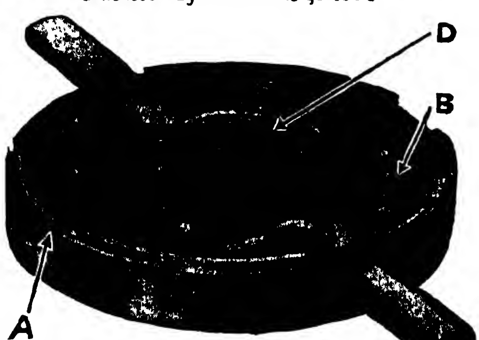
There is an astonishing variety in the methods whereby a wireman may plan or lay out his circuits. The superior way, probably, is to serve a multiple rectangular box placed in a strategic position amid the relative light and switch points and to radiate therefrom to the various points. On the branches from this box it is quite legitimate to employ other smaller branching boxes to lessen inordinately long loops. Of course, this method is not best adapted for lengthy circuits as in corridors or in extensive factory runs. Some wiremen accomplish all their circuit wiring without going beyond the utilization of circular 1, 2, 3 and 4-way boxes. These may be of the standard Universal type or something a little more roomy. This teeing method of circuit planning is specially convenient for surface wiring, although for conduit systems it entails larger sizes, as a rule. Both the above-indicated main principles in circuit lay-out are applicable with lead-sheathed and with tough rubber systems. With these, of course, it is not usual to adopt looping to the same extent as with conduit, and every box will contain a junction of some kind.

Joints and Connexions on Circuits. There is still nothing so reliable and lasting as the soldered and well-taped joints on circuit cables, although the modern thimble-shaped china connectors with tapered interior threads are wonderfully



WIRING. Fig. 9. Method of connexion of looping boxes with tapped holes, using brass bushes and solid couplers.
General Electric Co., Ltd., of England.





WIRING. Fig. 10 (above). Universal box for lead-covered cables. Fig. 11 (below). Joint box for non-metal-covered cables.
Sun Electrical Co., Ltd

good substitutes. The advent of A.C. has largely discredited the formerly common china connectors provided with set-screws. All joint boxes should be of a size and shape which provides a little slack at the cable ends. Employers often do not realize what martyrdoms are entailed by the effort to secure reasonably permanent contacts in nasty little boxes, especially in those types where pinching screws are employed on fixed china blocks. *See further under* Connexions *and* Joints.

Looping. The looping of wiring is a subject on which there has always been some difference of opinion. Looping is a method of avoiding joints, but nearly always introduces considerable additional cable. It is sometimes applied to sub-mains at distribution fuseboards, in which case to comply with I.E.E. Regulations there should be no diminution of cable sizes. Generally, looping is confined to sub-circuit work and in a more or less modified form to suit the particular conditions. When a sub-circuit is completely looped, all the junctions between cable ends are made at the light or switch or socket terminals. As an additional assistance in limiting excessive lengths of cable, switches and ceiling roses are available provided with three in place of the normal two terminals (*see also* diagrams, page 776).

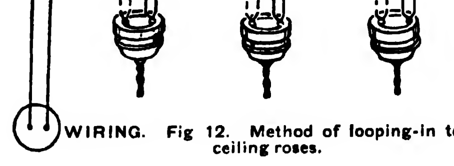
In factories, etc., where there are long rows of lights, it is obviously easier and better to bare an inch of cable at each ceiling rose and to bind the bared loop in the terminal rather than make two joints at each fitting. Again, at points where there are two or three branch switches together it is a simple matter to bare and double and insert the supply wire in the first switch, repeat with the following switch, and carry on to the third or final switch. These are typical cases where looping is the best method. Even then, however, the current for subsequent lights or switches has to pass through the small dry joint in the first looped terminal, sometimes causing undue heat. It is frequently necessary to cut away a strand or two of entering cables at the small hole in terminal and the danger of that is obvious.

When looping is applied to conduit work the sizes may have to be considerably increased to suit I.E.E. limitations of number of cables.

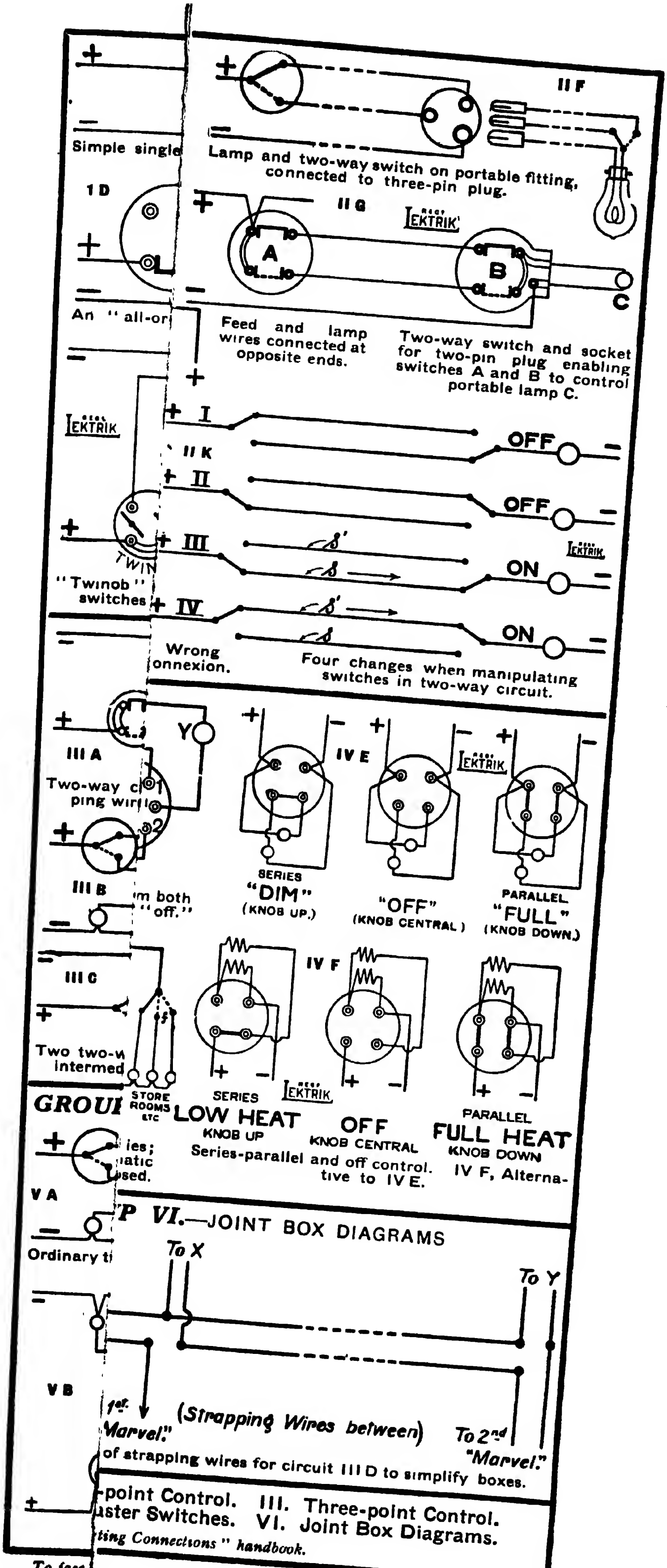
When applied with lead-sheathed cable or cab tire, consistent looping often calls for the use of single core cable.

On the other hand, looping is of advantage in the tracing of faults and lessens the need for examination of concealed junction boxes.

Wiring and Connexion of Fittings. Whenever possible, from the electrical point of view, it is desirable to carry the ordinary circuit cables direct without break through the bracket or ceiling fitting into the lampholder. Far more could be done in this regard if the makers



WIRING. Fig 12. Method of looping-in to ceiling roses.



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of electrical fittings would assist. Unfortunately, those men who specialize in design are apt to ignore the practical difficulties involved in wiring and connecting their products. Narrow 1½-inch backplates and ceiling plates offer trials to the electrician who has provided outlet boxes with standard 2-inch centres.

Square and triangular tube sections and sharp bends in fittings are among the causes of grey hairs on wiremen. Insult to injury is added when all the negotiations regarding fittings, including the financial, have been arranged without reference to the contractor. Fittings ordered by architects very usually arrive wrong length, wrong colour, wrong backplate, wrongly wired, and wrong method of fixing and wrong insulation test. But up they somehow go! Under modern supply conditions a greater proportion have to be earthed. So more attention must in future be given to practical points in fitting design. The writer has been saying this for twenty years.

On simple pendants and ceiling fittings some of the risks are got over by the increased popularity of bakelite in place of brass. For outside or watertight fittings all-china holders are superior to others. Such fixed fittings and those near exposed conduits, stone floors, water or gas pipes should, of course, be earthed to comply with regulations. The need for earthing under such conditions is equally imperative for portables.

Good quality flexible cord should always be used for fittings, and on no account on 3-core flexible should any core other than the " White " be used as the earth connexion. Joints between flexibles and hard wires should be made by means of china connectors, especially in these days when fashionable people need to change their fittings every season, and the cleanly class finds that all the colour comes off the sprayed glass creations in the wash.

Planning Wiring. The wise architect submits his building plans at an early stage to a competent installation engineer and weighs his advice with regard to adequate spaces and roads for the electricity installation. Mostly, architects act otherwise, however, and seem to forget all about the electrician until the last minute, with the result that the difficulties and costs are increased.

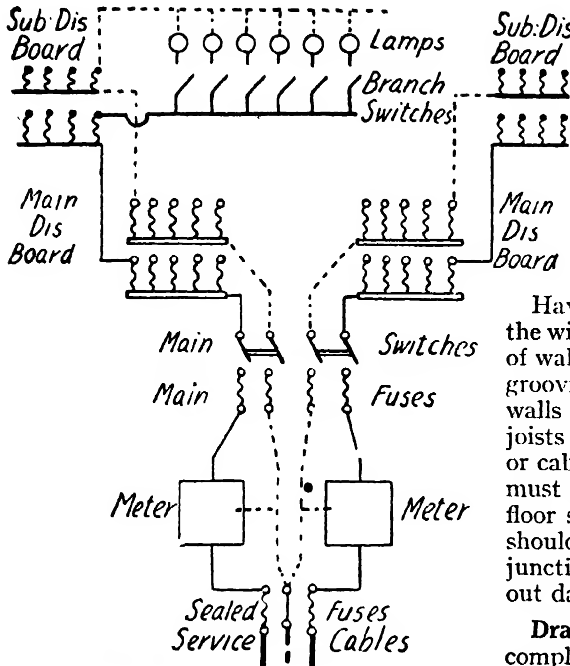
Estimates for electrical work are often accepted before the contractor has had more than a somewhat grudgingly granted glance at the plans, but he generally receives a set along with the letter of acceptance.

The plans are handed to a foreman, who proceeds to pore over them and mark in likely places for the fuseboards, etc., and measures up the lengths for mains and sub-mains. It is rarely wise at this stage to do much circuit planning. To a practical electrician the best methods of dealing with the sub-circuits suggest themselves on the site. There may, for instance, be stone, rubber laid, parquetry, or tessellated floors which call for special floor boxes or the adoption of draw-in methods between switch and fitting box without the intervention of other junction or draw box. The plan probably does not indicate where such floors are. Nor may it show what space is available below floorboards.

Procedure and Practice

In many cases with small and medium-sized private and business installations no special plans are prepared. Accompanied by the prospective consumer one goes round the various apartments and marks on wall and floor the proposed positions. When directed to proceed with work it is necessary to fill up and get the consumer to sign an application form for the supply undertakers, giving the number and sizes of lamps, radiators and the like, and stating whether a special circuit is wanted for cooker. The supply undertakers will then send to point out the position of the service and at which point they will fix the sealed service fuses and meter. Very often the undertakers do not earth these appliances, but this bad example must not be imitated elsewhere on the installation.

As near as possible to the service fuses the main switch or switches should be erected. In selecting the type of switch, it may be kept in view that a positive action and avoidance of light springs is desirable in a piece of apparatus which may not be operated for ten years and then only in emergency. Between the service fuse and the main switch, which is generally of the switch-fuse type, a suitable iron inspection box with side outlet should be provided



WIRING. Fig. 13. Three-wire service diagram on distribution fuse system.

For the sub-circuits for lighting with an average of eight lamps, 3/·029 cable is quite sufficient, and for mechanical as well as electrical reasons this size should be adopted as a minimum for the normal standard 230-volt supply. For house radiators it is a general good rule to have separate 7/·029 circuits led to each 15-ampère switch socket.

Having selected the distribution points, the wireman may proceed with the cutting of wall holes for the outlet boxes, with the grooving of brick, stone and concrete walls and with the neat cutting of the joists and beams for underfloor conduits or cables. With regard to the latter, care must be taken to avoid weakening the floor structure and screwed lifting boards should be arranged over each concealed junction box to provide future access without damage to the flooring.

Drawing-in. When the conduit system is complete and plasterwork dry, the cables are drawn into position. This is an easy matter if work has been well arranged. Although it may have taken a squad of men a month to install the conduits in a particular building, the actual pulling-in, or preferably pushing-in, of all the cables may be accomplished in one day. It is not always appreciated that a help for

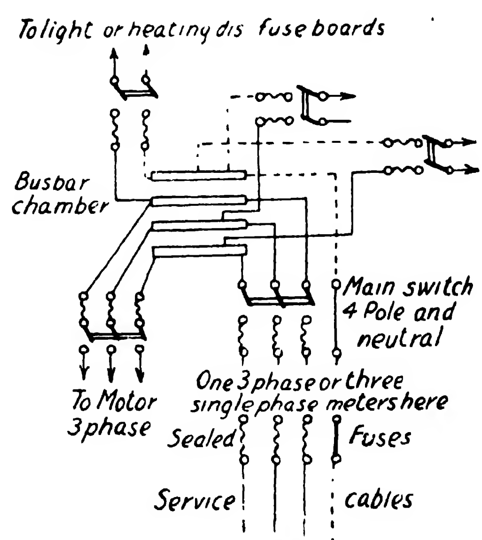


Fig. 14. Four-wire service diagram on distribution fuse system.

for the meter bight. Near here, also, it is desirable to make the main earthing connexion for the cable which runs to the main cold water supply pipe. The earth cable must never be less than 7/·029, and if the main cables are larger than that, must be at least half their size. The quality, capacity and permanence of the earthing arrangements are generally a fair guide to the capabilities of the wireman.

Distribution Boards. With more than one distribution fuseboard it is best that these be fed through a suitable main distribution fuseboard. In many houses it is desirable to have two distribution boards for the lighting. It is expedient in such cases to loop from one distribution board to the other or from the main switch terminals to the boards.

The distribution boards should be placed in conveniently accessible positions on each floor and not fixed in dark closets where inflammable materials are stored. It is advisable to have at least two spare ways on each board. The sizes of main switches, fuseboards, mains and sub-main cables should be ample to carry the full load on each board.

the more difficult runs is to insert a steel draw wire of 18 S.W.G., to which the ends of the cables are hooked.

After the wires are in place and the joints or connexions made, the painters and decorators proceed with their surface work, and finally the wiremen erect their switches, plates and fittings. Too often keenness of price is a motive in hurrying on the erection of switches and the like and damage is caused at the very beginning by painters splashing these in their operations or by their removing and replacing covers in an unskilled way.

In the general course of the work every care must be taken to prevent damage to finished wall surfaces, etc., to avoid candle grease drips on floors, scratches on furniture and other uncouth evidences.

Tests. When the insulation tests are applied first by the erector and later by the supply inspector, the insulation resistance should show not less in megohms than 50 divided by the number of outlets. No single circuit should fall below one megohm, and detached apparatus as radiators or motors must be of greater resistance than half a megohm.

The continuity test from the metal cable sheathing or for the conduit system from a point near main switch to any other part of the installation should not exceed 1 ohm. These conditions are by no means onerous, and better results may be looked for on most jobs which have been fitted with reasonable care.

Wiring in Large Buildings. Most of the new big office and flat structures are affairs of steel and concrete and their architects are gradually realizing that the provision of adequate spaces and runways for conduits and controlling appliances is part of their job. The importance of provision for electrical service has long been more completely realized by the designers of American skyscrapers. Over there a basement floor is often entirely set apart for transformers, oil switches, and control gear. Ample vertical and horizontal runways are provided for lighting, heating, signalling, telephone, radio, etc., services, and the sky floor is devoted to lift and supplementary electrical appliances.

On lofty buildings very appreciable heat may be generated by the rising feeders, so these are often of paper insulated armoured type, so treated that their liquid content does not tend to flow downward. They may even be simple copper rods wrapped in mica compound if the architect has been sympathetic enough to provide appropriate, wide, well-ventilated channel shafts.

It is considered permissible that a comprehensive type of underfloor raceway

Fig. 15

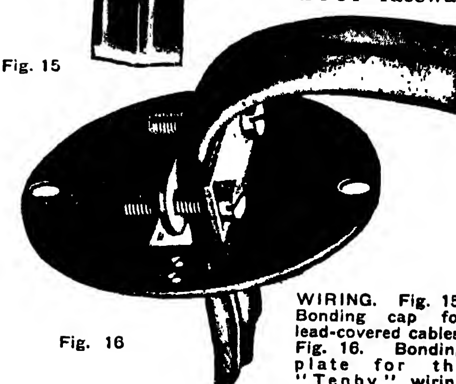


Fig. 16

WIRING. Fig. 15. Bonding cap for lead-covered cables. Fig. 16. Bonding plate for the "Tenby" wiring system.
S. O. Bowker, Ltd.

be embodied for signalling, lighting, power, heating, etc., provided the differing cable systems are run in obviously separate compartments. Such conduits must, of course, be of ample size to meet all likely additions. Floor boxes for the different electrical systems should be quite distinct, although a group of these may have, desirably, one upper and overlapping lifting floor panel, easily located.

Hazards of Wiring. The insulating substances used are continually being subjected to electrical stress. This in itself is a deteriorating influence and the action is relatively rapid with inferior elements and compounds. The chemical structure of all wiring materials also undergoes some gradual changes quite apart from electrical causations. These minor hazards of wiring are to some varying extent inherent in any given installation even when conditions are most favourable. Cheap unsuitable

substances and half-hearted workmanship naturally accentuate the category of evils which arise from within.

The most common outside dangers to be guarded against in all normal work are damp, dust, direct sunlight, corrosive plasters, vermin, insects, vibration and mechanical damage. Common-sense protection expedients suggest themselves whenever any of the above-listed jeopardizing agencies are particularly to be anticipated. A little extra protection with steel or lead, the application of insulating tape, varnish or anti-corrosive paint, and suchlike obvious measures applied with forethought here and there on an ordinary installation, may prolong its useful life for many years.

Very special or extreme means of protection have to be adopted sometimes. In acid factories and the like wiring is occasionally run in a system of ebonite conduits. In certain parts of breweries tough rubber makes the best job. In ships the metal sheathing must be of that particular lead, antimony, cadmium alloy which best stands up to constantly trembling clips and saddles. Where corrosive waters, urine and decayed vegetable and animal matter are present, as in new housing areas, abbatoirs and farms, lead-covered cables are indicated, but they should preferably be coated with bitumen, which is probably the most stable chemical compound used for insulation. In practice, the bitumen is generally applied in the form of impregnated hessian or jute serving, and these being of a vegetable nature are themselves liable to decay. In time the cable makers will find a way of satisfactorily applying bitumen mixtures without the jute. Just as the brick-makers now do without straw.

In places where there are explosive gases, gas-tight fittings and switches are called for ; the wise wireman will not rely too much on a name, however, in such cases, and will provide D.P. branch switches and keep them as far as possible from the low-flashpoint area. Really dangerous situations, however, are as a rule treated with elaborate respect and the materials and arrangements given their due weighty and expensive consideration. In the aggregate, much more damage to wiring is caused by careless fitting, by water, by mice, by lap dogs and by the lady hanging pictures. The minor hazards of wiring should be always kept in mind when installing.

WIRING REGULATIONS. The following extracts from the I.E.E. Regulations for the Electrical Equipment of Buildings comprise the main requirements for ensuring satisfactory results, including safety from fire and shock, and are supplementary to the Home Office Regulations (*q.v.*) and the regulations issued by other authorities, such as licensing authorities for theatres and other places of public entertainment and resort.

The 10th edition of the Wiring Regulations is arranged in fourteen sections, each comprising an aspect of the suitable installation and distribution of supply for voltages not exceeding 650 volts. Section 1 covers the control and distribution of supply ; section 2, the arrangements of final sub-circuits ; section 3, conductor and cable requirements ; section 4, the installing of conductors and cables ; section 5, temporary installations ; section 6, accessories and lighting fittings ; section 7, the installing of current-using appliances ; section 8, the installing of electric signs and luminous discharge tubes ; section 9, valve amplifying and radio apparatus ; section 10, earthing ; section 11, the testing of installations ; section 12, the installing of private generating plant and secondary batteries ; section 13, construction of electrical apparatus ; and section 14, tables of electrical properties.

It would, of course, be impossible in a work of this nature to reproduce in full the text of all these sections, and therefore a representative selection has been made of section 4 as proving of most interest to the working electrician. Other extracts from the regulations are interspersed throughout this work, however, under representative headings. It should be stated perhaps that in every case these extracts or references are made in conformity with the 10th edition of the Wiring Regulations and by permission.

SECTION 4. INSTALLING OF CONDUCTORS AND CABLES

Cleated Wiring

REGULATION 403. Braided vulcanized-rubber-insulated cables may be used without the further protection of conduit or casing provided that :

(A.) They are open to view throughout their length, and, in particular, are not installed under floors or within partitions or buried in plaster.

(B.) They are prevented by spacing, insulation, or other means from coming into contact, under any conditions of service, with any other conductor, or with earthed metal, gas pipes or water pipes.

(C.) They are secured by porcelain cleats, or by clips, saddles or clamps which are so spaced as to prevent the cables coming into contact, and which have smooth or rounded edges that will not indent or damage the braiding.

(D.) In damp situations the supports and fixings are of non-rusting material

(E.) In any position in which they would be liable to mechanical damage, and wherever they are within 6 feet above the floor, they are adequately protected.

(F.) If passing through floors, walls, partitions or ceilings they pass through directly and are protected by being enclosed in metal, porcelain or other non-absorbent, non-ignitable conduits, the ends of which are bushed or so arranged as to prevent abrasion of the cables; and in the case of walls and floors the holes through which the conduits pass are made good with cement or similar incombustible material to the full thickness of the wall or floor, no space through which fire might spread being left around or inside the conduits.

The protective conduits, if isolated, exposed, and of metal, shall be earthed by efficient means, but not necessarily near the point of entry of the supply.

Flexible Cord

REGULATION 405. Where flexible cords are provided for fixed wiring they shall be installed in compliance with the following requirements:

(A.) They shall be used only for sub-circuits carrying currents not exceeding 6 ampères and having a voltage not normally exceeding 250 volts.

(B.) They shall be open to view throughout their length, except where protected in accordance with specified conditions, and in particular they shall not be installed under floors, or within partitions, or buried in plaster.

(C.) They shall be prevented by spacing, insulation or other means from coming into contact, under any conditions of service, with any other conductor or with earthed metal, gas pipes or water pipes, and they shall not be installed below the last, or exposed to drip due to condensation or other cause.

(D.) They shall be supported on effective insulating cleats fixed at intervals not exceeding 3 ft., such cleats being so designed and placed that the cords are securely fixed and permanently spaced away from walls, ceilings and structural metal work. The insulators shall have smooth or rounded edges that will not indent or damage the cords.

(E.) If insulated with pure rubber only they shall not be used in damp situations.

(F.) In damp situations the supports and fixings shall be of non-rusting material.

(G.) In any position in which they would be liable to mechanical damage, and wherever they are less than 6 feet above the floor, they shall be adequately protected.

(H.) See 403 F.

Armoured and Metal-Sheathed Cable

REGULATION 406. Armoured and/or metal-sheathed cables may be used without the further protection of conduit or casing provided that

(A.) They are prevented by spacing, insulation or other means from coming into contact, under any conditions of service, with gas pipes or water pipes.

(B.) If liable to mechanical damage they are adequately protected having regard to the nature of their sheathing.

(C.) They are secured by clips, saddles or clamps constructed of such material as will not be liable to set up electrolytic action with the sheathing and having smooth or rounded edges which will not indent or damage the sheathing.

(D.) The spacing of the clips, saddles or clamps should be such as would prevent appreciable sagging of the cable if fixed horizontally to the surface of a wall.

When vertical, cables are fixed by the same means, with supports at the same intervals.

(E.) If they are inaccessible, a length not exceeding 10 feet may be allowed between the supports. In the latter case the upper support shall firmly grip the cable or wire, and where there is a change of direction from horizontal to vertical the cable shall be brought over a rounded support of a radius of not less than six times the external diameter of the sheathing for vulcanized-rubber-insulated and eight times for impregnated-paper-insulated whether armoured or not.

(F.) In damp situations and where exposed to the weather the saddles and fixings shall be of non-rusting material.

(G.) When passing through walls or fire-resisting floors, the holes through which they pass are plugged with fire-clay or similar non-ignitable material; and where passing through steel or iron structural work, the holes through which they pass are bushed to prevent abrasion.

(H.) When run under floors or behind partitions all connexions are made in boxes of ample capacity and of non-absorbent, non-ignitable material.

(I.) Effectual means are taken to ensure that all metallic envelopes of cables are efficiently earthed and made electrically continuous throughout their length by means of soldered joints or, alternatively, by bonding clamps specially designed for the purpose or forming part of joint boxes and similar fittings in which the cables terminate. The electrical resistance of the metallic envelope of cables in a complete installation, measured between such envelope from the connexion with the earth electrode to any other point of the installation, does not exceed 1 ohm.

Conduits

REGULATION 408. All classes of cable may be enclosed in steel conduits provided that

(A.) The conduits are installed in accordance with the requirements of Regulations 1319–1322 inclusive.

(B.) The conduits of each circuit are erected complete before the cables are drawn in.

(C.) The conduits are prevented by spacing, insulation, or other means, from coming into contact, under any conditions of service, with gas pipes or water pipes, and if liable to mechanical damage, are adequately protected.

(D.) The conduits shall be so installed as to avoid as far as possible the condensation of moisture within them.

(E.) No elbows or tees, unless of the inspection type, are used, except at the ends of conduits immediately behind fittings or accessories; and no bend has a radius smaller than 2½ times the outside diameter of the conduit.

(F.) Provision is made at the ends of all conduits to prevent abrasion of the covering of cables emerging therefrom. The ends of conduits where terminating at accessories and fittings are screwed thereto or provided with lock-nuts, or are led into separate blocks, preferably of non-ignitable material.

(G.) (See 403 F.)

(H.) (See 406 H.)

(I.) In damp situations, and where exposed to the weather, the conduits are welded, brazed or solid drawn; and saddles and fixings are of non-rusting material or finish.

(J.) The conduits are mechanically and electrically continuous across all joints therein and are earthed in accordance with Regulations 1001–1008.

The electrical resistance of the conduit in a complete installation, measured from the earth electrode to any other point of the installation, does not exceed 1 ohm.

(K.) Inspection and draw boxes are of metal and are rigidly connected to the conduits by means of screwing or by nuts on both sides of the wall of the box.

Earthed Concentric Wiring

REGULATION 412 (A). Earthed concentric wiring shall only be used when connected to systems of supply:

(*a*) So as to derive the supply from the secondary side of transformers or converters so arranged that the public supply system is electrically insulated therefrom; or

(*b*) In which earthed concentric wiring has been approved by the Electricity Commissioners; or,

(*c*) Consisting of an independent generating plant.

(B.) A cut-out, non-linked switch or non-linked circuit breaker shall not be inserted in the external conductor.

(C.) The external conductor shall be earthed, and if the supply is D.C. the external conductor shall, where possible, be negative to the internal conductor.

(D.) From the position or positions at which the installation is earthed, concentric wiring shall be employed throughout up to all fixed positions for fittings or accessories. At all positions at which the external conductor ceases to surround the internal conductor the latter shall be separated from the surface upon which the fitting or accessory is mounted by an incorrodible metal plate or terminal box to which the external conductor is electrically connected. This requirement does not preclude the interposition of a wooden block between the metal plate and the fitting or accessory mounted thereon, provided that this metal plate covers the principal recess in the wooden block.

"X." Symbol adopted for Reactance (*q.v.*), the component of the impedance due to capacity or inductance effects. Also used in the plural as the abbreviation for atmospherics in wireless work.

X-RAY APPARATUS IN MODERN WORK

By E. H. W. Banner, M.Sc., A.M.I.E.E., F.Inst.P.

This article is necessarily almost complete within itself as being concerned with a highly specialized subject. It covers both medical and industrial uses of X-rays. Other medical applications of electricity are considered under Diathermy and Ultra-Violet Apparatus. See also Coolidge Tube; Crookes Tube; Electron; Gaseous Discharge.

Whilst there has been some recent controversy over the nature of X-rays, it is generally accepted that they are electro-magnetic waves of the same nature as those of visible light, wireless waves, etc., but their wavelength is much shorter than the visible light rays.

The wavelength range extends from about 1 to 0·05 Å. (Å is the Ångström unit and equals 10^{-10} metre, or one millionth of a millimetre.) This is for the range of X-rays used in medicine and in industry. The total range is much wider and practically joins the far ultra-violet at one end and the γ-rays of radium at the other; *i.e.* about 500 to 0·05 Å.

X-rays travel in straight lines similarly to light, but cannot be reflected or refracted, neither can they be deflected by an electric or a magnetic field, although cathode rays are deflected by such forces. X-rays are generated when cathode rays are stopped by impinging on a material of relatively high atomic weight. Cathode rays are electrons and are emitted from a hot filament, and if a second electrode is in the vicinity and maintained at a positive potential with respect to the cathode,

electrons will be drawn towards it and a flow of current takes place.

As with the cathode ray oscillograph a hot cathode is not essential for the generation of X-rays ; if a sufficiently high voltage be applied electrons are drawn from the cathode and X-rays generated when these strike a suitable body or " target." Early X-ray tubes were " gas " tubes in that they contained air at low pressure, whereas almost all modern tubes are thermionic, containing air or other residual gas at a very much lower pressure, so that there is no measurable conduction unless the filament be heated.

The electrical supply necessary is a supply of high voltage. The actual voltage determines the penetrating power of the resulting X-rays, together with the nature of the metal of the target.

Effects of X-Rays. The effects of X-rays are physical, chemical and biological. One example of the physical effect is that if X-rays fall on a spark gap the resulting voltage necessary to spark over is lower than without the X-radiation ; the rays " ionize " the air or make it conducting. The fluorescence of certain minerals is also a physical effect. Chemical effects are mainly shown by the effect of the rays on a photographic plate, whilst the action on the human body is the biological effect.

X-rays are like most things in their physiological action in that whilst properly controlled and applied they are beneficial ; when they are indiscriminately applied harm results, even loss of life ; the effects are very slow but cumulative.

Applications. The two applications to medicine are therapy and radiography, but the latter is really subdivided into radioscopy (or fluoroscopy) and radiography. For industrial applications these latter two applications only are utilized. Therapy is X-ray treatment. Radioscopy, or fluoroscopy, is the examination of a solid and opaque body by X-rays when the rays passing through cause a fluorescent screen to show the rays as shadows. Radiography proper is the taking of X-ray photographs, either in medical (and surgical) or industrial use.

Whilst X-ray apparatus is more or less the same for each of the above purposes, it is more convenient in practice to separate the apparatus into two, therapy and radiography, the latter serving both fluoroscopy and radiography. A further use of X-rays is in crystal analysis, where a means of the examination of the structure of matter is now available that was impossible before knowledge of X-rays. Considerable knowledge of the structure of matter has recently become available due to X-rays.

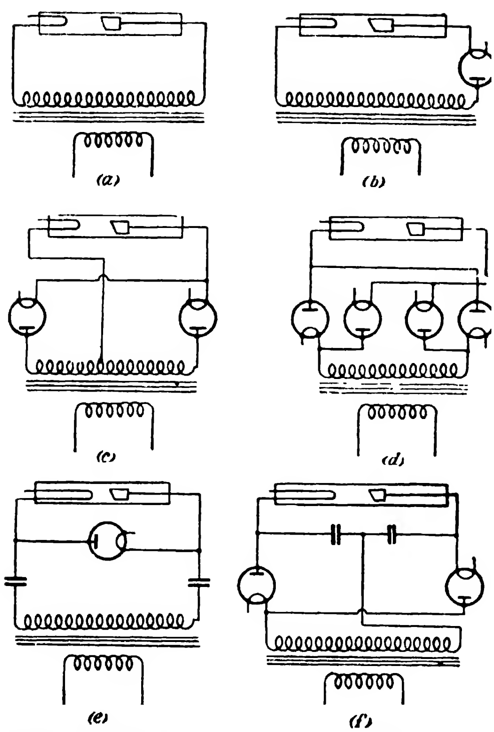
THE APPARATUS EMPLOYED

The essentials comprise only some form of high-voltage generator and an X-ray tube. In practice other apparatus is also necessary for most cases.

As the thermionic X-ray tube only passes current when the anode is positive with respect to the cathode, it is a rectifier. On the other hand, in use, the anode of an X-ray tube gets hot, and if it gets sufficiently hot to emit electrons of its own the tube is no longer a nearly-perfect rectifier, and the emitted radiation is spoiled, so that the effective output of X-rays falls off. Except for very small sets, it is usual, then, to rectify the supply so that the tube does not have to rectify in addition. Thus the apparatus is now a high-voltage D C. generator—actually unidirectional—and the X-ray tube.

Further apparatus is involved in control gear and means for supporting the patient or work relative to the tube, etc. Early generators comprised an induction coil with hammer interrupter run from batteries, and a crude form of rectifier comprising a point-plate spark gap in air or in vacuo. Afterwards, motor-mercury and electrolytic interrupters replaced the hammer, and mechanical rectifiers rectified the secondary current. Now the practice that is almost universal is to transform to the required voltage from A.C. mains, and to rectify by means of a thermionic valve, although in America mechanical rectifiers are still used.

It has already been stated that the voltage used to generate the rays determines the penetrative power of the rays. For crystal analysis the voltage may be only about 40 kilovolts, whilst for medical radiography 60–100 kV is usual, and for therapy about 200 kV. Industrial radiography requires voltages depending on the job in hand, relatively thin and



X-RAY APPARATUS. Fig. 1 (*a*). Unrectified circuit. (*b*) Single valve, half-wave rectified. (*c*) Two valve, full-wave rectified. (*d*) Four-valve, full-wave rectified. (*e*) One valve and condenser, Villard-pulsating double voltage supply. (*f*) Two valve and two condenser, Greinacher-constant double voltage supply.

transparent articles requiring, perhaps, 50 kV, whilst for thick steel specimens the highest obtainable voltage is necessary. Upwards of 400 kV are used, but such installations are not common.

Rectifiers. Rectifiers for X-ray plants may comprise a single unit for half-wave rectification, two units with a centre-tapped transformer, or four valves with a standard transformer for full-wave rectification. Also, three-phase mains may be used with six valves for full-wave rectification. In addition, although elaborate smoothing, as used for radio sets, is not necessary, some installations include one or more condensers for some degree of smoothing, so as to obtain a constant voltage supply.

For the majority of work a single valve, giving half-wave rectification, is used on account of its cheapness. Two-valve sets are uncommon, and four valves, although used to some extent, are expensive. It is true that the half-wave set is less efficient, and that the load on the supply mains is not normal; but as the efficiency of generation of X-rays by the X-ray tube is less than 1 per cent., the extra inefficiency is not serious.

X-Ray Set Circuits. Some of the usual circuits for X-ray sets are shown here. Fig. 1 (*a*) shows a set with no rectifier, the tube itself performing this function; it is usual only for small-power sets, such as for physical work and dental radiography. Fig. 1 (*b*) shows the usual single-valve set, and Fig. 1 (*c*) the uncommon two-valve full-wave set. Fig. 1 (*d*) is the usual full-wave arrangement using four valves in a bridge connexion. Fig. 1 (*e*) shows a circuit due to Villard, and using one valve and a condenser. The voltage is doubled and rectified, but is pulsating, as it is only half-wave. Fig. 1 (*f*) is the Greinacher circuit using two valves and two condensers for voltage doubling and smoothing.

Another type of generator occasionally used is a condenser set. A high-voltage condenser is charged from the mains through a transformer and rectifier, charging occupying several seconds. For an exposure the condenser is suddenly discharged through the X-ray tube so that a high power results, but due to the slow charging there is no heavy current rush from the mains. This type of generator is only available for radiography, as it does not give a sustained output.

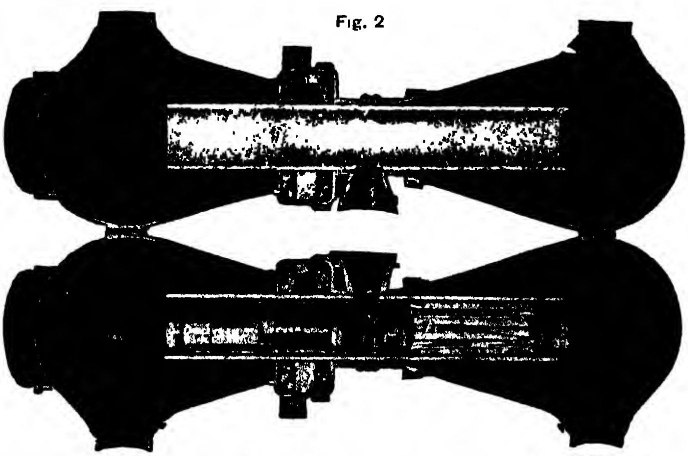
X-Ray Tubes. The two general types have already been stated as the gas and the thermionic. The latter is that used almost exclusively, and it has two general forms, being either in a glass envelope as designed by Coolidge or a metal and bakelite case, the metal of the latter serving as X-ray protection. The earliest practical example is the Philips Metalix (Fig. 2), and the British "Protexray" tube (Fig. 3) is generally similar.

Rays are emitted from the surface receiving the cathode rays; this electrode is positive, and so is called the anode. The active part of the anode, that which receives the cathode rays, is called the target, and it is generally of tungsten, a metal with a high melting point. In use the target gets very hot, so that the main body of the anode is made of copper, so as to have a high heat capacity. Glass

tubes are the original type, and require X-ray protection so that the radiation is only finally emitted where it is required. The metal tube is of later origin, but is now nearly universal in this country. It contains lead around the anode, with the exception of an aluminium or glass window for the rays to emerge. Consequently such tubes do not need to be housed in lead-lined boxes, and so are less bulky.

For prolonged running the anode gets so hot that it limits the work that can be performed. To overcome this some tubes are water-cooled and have a circulation of water running to and from the anode. The rating is thereby increased. Another design employs a rotating anode, so that, although the part of the target in use at one time is small, the total surface receiving radiation is large, so that more heat may be dissipated without harm. The necessity for a small active target is in order to obtain "definition" of the resulting radiograph, almost exactly as in a photograph where a small lens aperture improves the sharpness of the resulting picture.

Fig. 2



X-RAY APPARATUS. Fig. 2. Exploded and sectional views of the "Metalix" tube.
Philips Lamps, Ltd

Fig. 3. Exploded view of the "Protexray" tube showing ray aperture
Cuthbert Andrews, Ltd

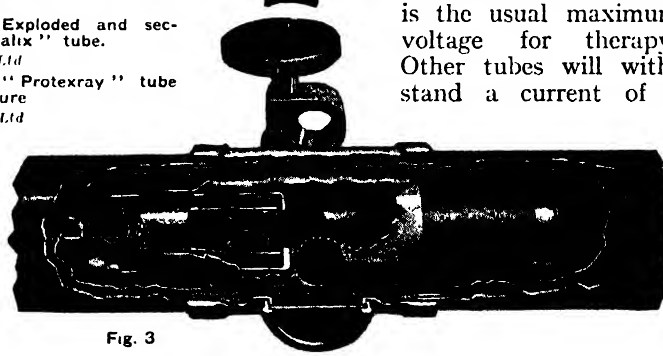


Fig. 3

X-Ray Loadings. Common ratings for X-ray tubes are as follows—3, 6, and 10 kW. These ratings are ambiguous, as obviously the time of operation has to be considered as the anode heating limits the load.

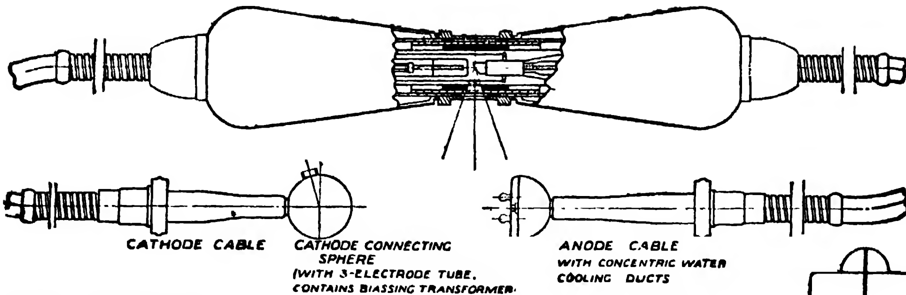
Examples of various loadings and times for a 3-kW tube are :

kV, r.m.s.	1 sec.	10 sec.	20 sec.	5 min.
80	37 mA	28 mA	22 mA	5 mA
60	50	37	29	5
40	75	56	43	5

Thus, if the voltage is 60 kV and the current 50 mA, the safe time of operation will be 1 second. The product of kilovolts r.m.s. and mean milliampères is general, although it has no real significance for other purposes. It is used because the peak voltage determines the penetration and also because early apparatus used a spark-gap to approximate to the voltage used and in this way the peak voltage is that indicated. Similarly for current, a moving-coil milliammeter is always employed and this instrument reads the mean value of a rectified current.

Other and special tubes are made for operation at 400 kV and even 800 kV, but 200 kV is the usual maximum voltage for therapy. Other tubes will withstand a current of 1 ampère for a fraction of a second.

The rotating anode tube illustrated in Fig. 5 consists of an anode in the form of an open cylinder and able to rotate inside the tube. Outside the tube is the stator of a small induction motor. When three-phase current, or single-phase with a phase-splitting device, is applied the rotor



X-RAY APPARATUS. Fig. 4. Constructional principles of the " Metalix shock-proof deep therapy tube.
Watson and Sons, Ltd. (Philips' Metalix patent).

revolves and so exposes a fresh part of its end, the target, to the cathode stream.

X-rays generated at low voltages are termed " soft " and at high voltages " hard " ; the terms are relative rather than actual, however. Whilst a high-voltage tube will generate hard or soft rays according to the applied voltage, a tube only designed for low voltages will only generate soft X-rays. Soft rays have a greater effect on the skin than hard rays, and are those used for therapy in certain skin diseases, whilst the very hard rays generated at 200 kV and above are suitable for deep-seated organs ; such sets are commonly spoken of as being suitable for deep therapy.

Shock-proof Apparatus. Danger of two types exists with X-ray generation ; danger from the rays and danger from electric shock. X-rays applied for a long time to the skin cause a form of burning or skin disease which is sometimes fatal. It is always long delayed and does not occur with a few short exposures such as a patient may obtain. On the other hand, electrical danger is directly serious and modern plants comprising high-efficiency transformers with almost unlimited power available from the mains are definitely dangerous, although the working voltage may be no more than in the old induction coil apparatus.

Protection from X-rays is achieved by the metal X-ray tube, or the lead-lined box of the glass tube. Lead-rubber is a useful material that is insulating and X-ray proof if sufficiently thick. Lead glass is also useful for some purposes.

Electrical safety has been provided in the past by isolating live leads as far as possible, but a much better way is now common. The live terminals of the tube are complely enclosed with earthed metal or with insulating material, and high-voltage rubber cables, having an outer earthed metal sheath, are used to connect the generating plant to the tube. The generating plant itself is either enclosed in an earthed metal cage or is in a separate room altogether, forming a high-voltage substation.

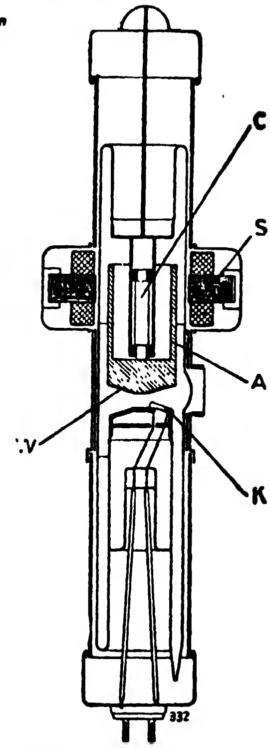


Fig. 5. The " Rotalix " tube in section. A, anode(rotating); W, tungsten target ; C, axis; K, hot cathode; S, laminated iron core.
Watson and Sons, Ltd., under Philips' Metalix patent.

This latter arrangement is only usual for very large high-power plants. For portable apparatus the best arrangement is one in which an earthed metal tank contains the transformer and the tube, self-rectification being employed. Here only the low-voltage leads are exposed and safety is a maximum. If the centre point of the system is earthed, then if 100 kV is used each high-voltage cable only has to be suitable for 50 kV to earth.

Controls. The penetration of the rays through any given object is proportional to the voltage, generally the peak voltage, but in some circumstances the r.m.s. value determines this. It is also

inversely proportional to the atomic weight of the material. On the other hand, quantity of radiation is proportional to current and time. The milliampère (mean) being a convenient unit, exposures are thus expressed in terms of milliampère-seconds.

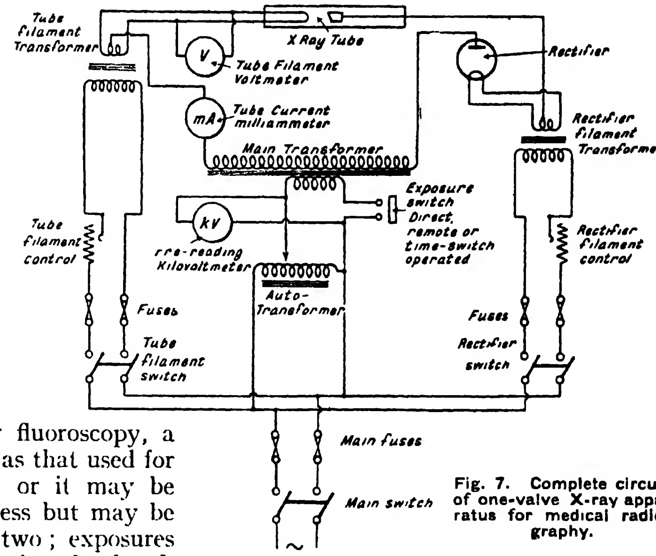
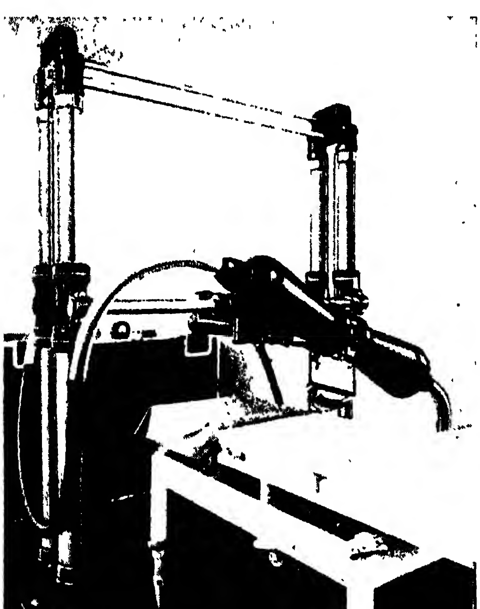


Fig. 7. Complete circuit of one-valve X-ray apparatus for medical radiography.

Simple X-ray sets have only one or two voltages for the output and a fixed current; then exposure is proportional to time. For radioscopy, or fluoroscopy, a voltage of the same order as that used for radiography is necessary, or it may be lower. Current is much less but may be on for perhaps a minute or two; exposures of films, or radiography, on the other hand, requires a larger current for a shorter time. It is now rare to find exposures exceeding a second or so, with the exception of small portable sets.

These two requirements are generally met by the provision of "dual control," where two sets of control switches and rheostats select the voltage and current and are brought into use by a change-over switch. Operation of the change-over switch brings the plant into use for radiography without having to vary several controls, probably in darkness.



X-RAY APPARATUS. Fig. 6. Complete "Metalix" deep therapy outfit including gantry stand, for 200 kV., installed in one room.

Watson & Sons, Ltd.

Voltage is determined by the transformer; alterations may be either by primary or secondary tappings, by a hand selector switch or by contactors with remote control on large sets with an auto-transformer. Current through the tube is determined by filament temperature and this is controlled usually by a rheostat in the filament transformer primary. Tube filament voltage is measured by a low-range voltmeter, or the current measured by an ammeter, but this is used only for preliminary guidance, actual current as read on the milliammeter being used for adjusting the tube filament.

Rectifier filaments always require to be run at full voltage—reduced voltage causes their anodes to overheat seriously. Voltage is read by a pre-reading kilovoltmeter; this is a low-range voltmeter of the moving-iron type connected across the primary of the main transformer where an auto-transformer is used to vary the high voltage. In this way it reads the voltage to be applied to the main transformer when the exposure switch is closed and it is calibrated in kilovolts. It is not

accurate, but it is sufficiently good for the purpose as it allows the operator to see what voltage will be switched on instead of switching on first and adjusting afterwards.

The actual circuits for sets by different makers differ considerably; one typical circuit for a one-valve plant is shown in Fig 7. As exposures are now so short it is common to find some form of time-switch where a control is adjusted either to a scale of milliampère-seconds or an empirical scale marked with parts of the body.

For X-ray therapy voltages of about 200 kV and currents of 4–10 mA are usual, the time of operation being for perhaps an hour or so nearly continuously. It is not usual to make one set serve for radiography and therapy on account of the differing requirements. Generally a valve and condenser set is used, or alternatively a three-phase six-valve set.

For industrial radiography sets are far more individual as, whilst a medical set will suit many hospitals and practitioners, a set suitable for examining steel cylinders is not suitable for examining wood for metallic inclusions, etc. The same general principles of controls apply, though a time-switch is unusual.

INSTALLATION AND MAINTENANCE

This is usually performed by the makers of the set, but it is occasionally a local job, particularly if it is a small set in a private house or a small hospital. The first thing is to find out if the supply is A.C. or D.C. If the latter a motor generator is almost imperative, as A.C. must be provided. Wiring requires to be such as to carry the current continuously and also so as not to cause an unduly high volt drop. A set giving exposures of 1 second will obviously require more current from the mains than one only capable of doing the same job in 20 seconds, so that in the first case the wiring must be larger. It should also be taken right back to the incoming mains, not tapped off the nearest circuit, otherwise objectionable light flicker will occur at switching on and off and also the set may be affected during an exposure by other circuits being switched on and off.

A double-pole switch with its fuses is necessary to control the whole supply; other switches for various internal circuits are provided on the control trolley. A good earth should also be provided for earthing the metal work of the control trolley, screening stand, etc., as recommended by the makers of the X-ray plant.

The smaller portable sets, of which the "Metalix" portable is an excellent example, require no additional wiring and may be plugged into the nearest A.C. supply. This is, of course, necessary for real portability for use in patients' houses. Such portable apparatus must of necessity be shockproof as well as ray-proof. The latter is secured by the use of the metal X-ray tube and the former by using high-voltage cables and enclosed tube terminals, etc.

Maintenance of sets includes checking the voltages of the filaments of the rectifiers. As the life of such a filament is of the order of 1,000 hours, replacements are necessary at infrequent intervals. During life the filament wears away so that if it is run at constant current it tends to become overheated. However, if an ammeter is provided by the makers this should be used and the current adjusted by the primary resistance to the nominal value. Voltage adjustment is preferable, however.

"Y" CONNEXION. System of connecting up three-phase windings. The circuits start from a common junction and their three ends go to the three lines. Alternative name for Star Connexion, under which the system is fully described.

"Y"-DELTA STARTER. Alternative for Star-Delta Starter, *which see*.

YOKE. The magnetic path of low reluctance between two neighbouring poles of a machine constituted by the cast-iron or cast-steel frame, and serving to carry the magnetic flux from pole to pole. In one type of machine, the yoke and core are cast in one piece, but more usually the core is cast separate and bolted to a machined seating cast on the yoke. In another construction the core consists of laminated iron sheets riveted together between end plates and cast into the yoke.

The latter type does not possess the advantage of permitting high density in the magnet core, for this would lead to uneconomically high air-gap density. The improved ventilation possible, however, has led to its successful adoption in many instances.

The flux density rarely exceeds 8,500 and 16,000 C.G.S. lines per sq. cm. in cast-iron and cast-steel yokes respectively. Firms supplying magnetic irons and steels issue magnetization curves from which the ampère-turns per pole required to send a given flux through the magnetic circuit may be obtained. The sum of the ampère-turns for each part of the magnetic circuits when found enables the designer to proceed with considerations of the stator winding. *See* Magnetic Circuits; Magnetization; Stator.

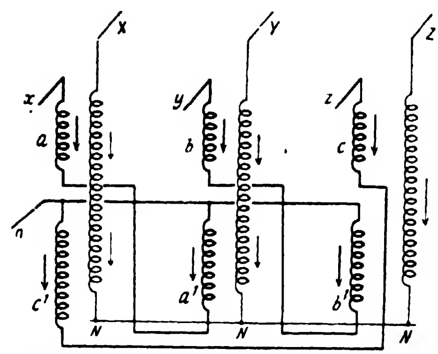
YRNEH. This term, which is Henry spelt backwards, has been proposed for the practical unit of reluctance, equivalent to $\frac{4\pi}{10^9}$ Oersteds. The latter is the proposed name for that reluctance through which unit magneto-motive force (*q.v.*) produces unit magnetic flux.

"Y" VOLTAGE. *See* Star Voltage.

ZERO METHOD. In the Wheatstone bridge and potentiometer circuits, measurements are made by adjusting the resistance ratios until no current flows and therefore no deflection is produced in the galvanometer. Such a method is more accurate than attempting to read values of deflection produced, into which parallax errors and other inconsistencies may be introduced. *See* Galvanometer; Potentiometer; Wheatstone Bridge, *etc.*

ZERO POTENTIAL. Since the potential of a body is usually compared to that of the earth, the latter is taken as being at zero potential, affording a convenient means of comparison.

ZIG-ZAG CONNEXION. Besides the standard three-phase star to star connexion, commonly adopted in transformers, there is a much less widely known method suitable for cases in which a variable part of the load is to be joined up between line and neutral. In such a case the loads may at times be very much out of balance, and



ZIG-ZAG CONNEXION. Three-phase star zig-zag transformer connexions.

if the high-voltage coils are also star-connected the system becomes unstable and severe unbalancing of the voltages results.

The star zig-zag connexion is clearly illustrated in the diagram. Both sides are star-connected, but on the low-voltage side half the winding of each phase is on one limb, and the other half on the next limb with connexions reversed. Thus for the "*x*" line half the winding *a* is on the X*x* limb and the other half a^1 is on the Y*y* limb.

About 15 per cent. more copper is used with this system of connexion and the secondary winding is more complicated and therefore more costly. The extra cost is, however, much more than saved on the star primary high-voltage winding which would otherwise have to be mesh. Moreover, an unbalanced load from lines to neutral does not render the primary unstable, the want of balance being distributed on the limbs. *See* Star Connexion.

ZIG-ZAG LEAKAGE. The leakage flux of any given motor may be divided into three parts, namely (a) peripheral dispersion; (b) end dispersion, including the self-induction field of the end connexions; (c) zig-zag leakage or dispersion.

The first-named is the leakage flux which passes from one pole to the other along the tops of the stator and rotor teeth, and therefore, of course, does not cut the rotor conductors. This is much diminished by using a large pole pitch, and would be greater in a motor with closed slots than in one with open slots.

The second is that flux which passes through the air from pole to pole at the ends of the motor, and also the self-induction flux around the end connexions of the stator winding. The latter is much increased if the end connexions are in close proximity to the iron of the stator housing or core.

The zig-zag leakage flux is so called because it passes peripherally along a stator tooth, crosses the air-gap, passes along the top of a rotor tooth, crosses the gap again, and so on until it reaches the adjacent pole.

Empirical formulae have been developed to obtain the dispersion coefficient or leakage factor (*q.v.*) which takes into account all the above effects. That due to Hobart states that

$$\text{Leakage factor} = a \times b \times \frac{\Delta}{\tau}$$

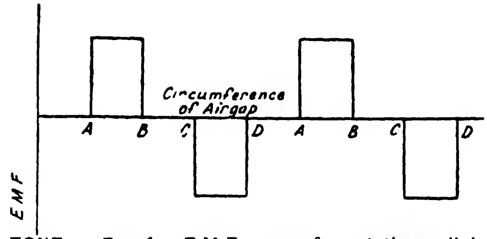
where a and b are constants depending on shape and size of slots and leakage effects, Δ is radial depth of air-gap in cms. and τ the pole pitch at air-gap in cms. These constants are obtained from curves developed from practical experience.

It is evident that the larger the number of slots per pole on rotor and stator, and the larger the air-gap, the less will be the zig-zag leakage effect.

ZINC-LEAD ACCUMULATOR. A special type of lead-sulphuric acid accumulator known as the Reynier cell, in which the zinc negative is employed in place of the usual lead plate. It is chiefly of academic interest and seldom employed in practice.

ZONE, NEUTRAL AND COMMUTATING. Considering a coil rotated between the poles of a permanent magnet, the changes in the current induced in the coil may be represented by a curve with the circumference of the air-gap as abscissa, and the E.M.F. induced when the coil side is at various points, as ordinates. Such a curve is illustrated in the diagram. BC and DA represent zones at which a transition occurs from positive to negative and *vice versa*, and during this transition no E.M.F. is induced in the coil. These zones are therefore referred to as neutral zones.

To obtain direct current supply from



ZONE. Fig. 1. E.M.F. curve for rotating coil in magnetic field. BC, DA represent neutral zones.

the coil, the latter must be connected to two insulated halves of a single slip-ring and the brushes be placed in the neutral zone, that is, they must touch the commutator at the extremities of a diameter perpendicular to the magnetic field. The current in the external circuit then flows in one direction only, and an intermittent direct current is thus obtained. In order that the intermittent current may remain constant in magnitude as well as in direction, the slip-ring must be divided into a greater number of parts and is then known as the commutator (*q.v.*), and in place of a single coil, many winding elements constituting groups of coils are employed.

As each winding element is short-circuited by a brush, the current in it is reversed. This reversal is retarded by the effects of armature reaction, and the self-inductance of the coils undergoing commutation (*q.v.*). If reversal is not

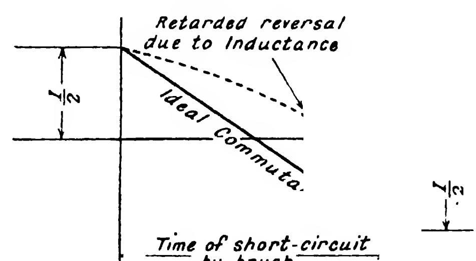


Fig. 2. Period of complete reversal of current marks the commutating zone.

complete when the brush leaves the old segment, a spark occurs. This means that complete reversal must occur during rotation of the commutator sufficient to cover the width of the brush. The commutating zone may, therefore, be defined as the angle swept out by the centre line of a slot during the time that the coils therein are short-circuited by the brushes.

END OF VOLUME IV

Classified Index and Reading Guide

Here the contents of the ENCYCLOPEDIA are brought under classified headings for the purpose both of grouping together associated aspects of particular subjects and of assisting the study of any branch of electrical engineering. This Index, with its cross references, is to be used in conjunction with the main cross reference system in the body of the Work. Thus, the general article on MOTORS: PRINCIPLES, TYPES AND CHARACTERISTICS, *outlines the whole subject with references to individual types. Under the heading* **MOTORS** *in this Classified Index will be found page references to all classes and types of motors as well as to other relevant articles. This Index does* not *supersede the general alphabetical arrangement and individual headings are* not *necessarily repeated here. Main articles are indicated by black type, thus:* **HIGH FREQUENCY 612·**